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BIOLOGY AND CHEMISTRY

CHEMICAL CHARACTERISTICS OF SOUTH-CENTRAL LAKE HURON

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Abstract. Water samples were collected for chemical analysis during eight cruises of the U.S. Bureau of Commercial Fisheries M/V CISCO in south-central Lake Huron in June-October 1956. Temperature, pH, conductivity, and the concentrations of Na^+ , K^+ , Ca^{++} , Cl^- , $\text{SO}_4^{=}$, SiO_2 , and dissolved oxygen were determined for 233 samples from stations at the mouth of Saginaw Bay and along a transect from Harbor Beach, Michigan, to Goderich, Ontario. The chemical composition, with the exception of silica, did not vary with season or depth. Water flowing into the lake from Saginaw Bay sometimes caused marked increases in the concentration of chemicals in surface samples at certain stations. Prevailing currents determined the location of these areas of higher salt concentration.

A chemical survey of the south-central portion of Lake Huron was undertaken for three reasons: relatively little chemical data existed for this lake; the data that were available came from water intakes or from surveys of short duration; data are needed to be able to compare present lake conditions to those in future years. Recent major chemical surveys of Lake Huron have been reported by the International Joint Commission (1951), Ayers et al. (1956), and Rodgers (1962).

Concentrations of the major chemical constituents in the Great Lakes have been used to demonstrate changes that have occurred in the lakes. Beeton (1961) related chemical changes in Lake Erie to the eutrophication of the lake. More recently, the changes in the chemical compositions of all the lakes have been considered (Beeton 1963). Since the Great Lakes have a large population and much industry bordering them, it must be expected that the concentrations of various chemicals in the lakes will increase as a result of the release into these waters of industrial wastes, sewage, and other byproducts of man's activities. Past records of chemical values for open-lake stations are needed if these changes are to be measured.

Personnel of the Bureau of Commercial Fisheries using the research vessel CISCO conducted eight 2-week cruises from June 3 through November 5, 1956, on Lake Huron and Saginaw Bay. On even-numbered cruises all stations were sampled (Fig. 1 and Table 1); on the odd-numbered cruises samples were taken only at 12 stations—62 through J. Samples were taken at the numbered stations at the surface and at depth with Nansen bottles, but at the lettered stations samples were taken only at the surface with a bucket while the vessel was underway. Results of sampling in Saginaw Bay have been reported previously (Beeton and Hooper 1961). Additional results of the 1956 survey were given in Johnson's 1958 report on currents of Saginaw Bay and Lake Huron as indicated by recoveries of drift bottles.

Analyses for Na^+ , K^+ , Ca^{++} , Cl^- , $\text{SO}_4^{=}$, SiO_2 , and specific conductance were performed on all samples of Lake Huron in the Biological Laboratory of the Bureau of Commercial Fisheries at Ann Arbor (Table 2). Dissolved-oxygen concentration and pH were determined immediately on samples taken in Nansen bottles. Sodium, potassium, and calcium concentrations were determined with a flame photometer (Beckman DU spectrophotometer). A titration with mercurous chloride and a diphenylcarbazone-bromphenol blue indicator was used for the chloride determination. Sulfate was measured turbidimetrically as



Fig. 1. Station locations for 1956, and surface currents during cruise I. Dot represents bathythermograph stations; triangle represents complete sampling stations. Dashed line represents the usual Lake Huron current and heavy line indicates the Saginaw Bay current based on drift-bottle data from Johnson (1958); squares show the release points and X's the recovery points of bottles.

barium sulfate, and silica was determined colorimetrically as the heteropoly blue. Conductivity was measured at the ambient temperature and corrected to 18°C by correction factors given by Smith (1962). Dissolved oxygen was determined by the unmodified Winkler method and pH was measured with a Hellige color comparator. Surface temperatures were measured with a Foxboro recording thermograph and subsurface temperatures with reversing thermometers.

The data indicated that an average of all the samples would not be truly descriptive of the lake since many samples showed the influence of the outflow from Saginaw Bay. The frequency distributions of ionic concentrations are skewed. The range of sodium values was 2.20 to 4.94 ppm but the average was only 2.67 ppm. Median values were held to be nearly representative of the usual composition of the lake. The median values for Lake Huron as determined for these eight cruises are: sodium 2.54 ppm; potassium, 0.85 ppm; calcium 26.7 ppm; chloride, 5.9 ppm; sulfate, 13 ppm; silica, 1.9 ppm; and conductivity, 174 micromhos at 18°C . These results, with the exception of calcium and silica, agree with previously published data (Ayers et al. 1956) and data compiled by Beeton (1963). The above value for silica is somewhat lower than those reported by Ayers et al. (Ayers, J.C., personal communication, values for silica, not silicon). The analysis used by Ayers was the colorimetric determination of the yellow silicomolybdate complex which yields values 1.1-1.4

times higher than those obtained by the present method. The calcium values are 2-3 ppm higher than those reported by Ayers et al. (1956). The reason for this discrepancy is unknown.

Table 1. Station Locations and Maximum Depths.
[Sampling was conducted at these locations during cruises II-VIII,
locations were slightly different during cruise I]

Station	Latitude (North)	Longitude (West)	Depth (meters)
62	44°15'30"	83°14'45"	33
A	44°16'15"	83°08'00"	65
B	44°16'45"	83°02'00"	75
C	44°17'15"	82°55'30"	82
D	44°17'45"	82°49'15"	71
63	44°18'45"	82°41'30"	66
E	44°14'45"	82°40'45"	58
F	44°10'00"	82°40'45"	54
G	44°05'45"	82°39'45"	48
64	44°00'00"	82°38'45"	33
H	43°56'15"	82°38'15"	26
J	43°53'30"	82°38'00"	16
K	42°50'30"	82°35'45"	18
L	43°50'15"	82°33'15"	35
65	43°50'00"	82°31'00"	46
M	43°49'15"	82°24'30"	66
N	43°49'00"	82°18'30"	68
P	43°48'15"	82°12'30"	68
66	43°48'00"	82°06'30"	91
R	43°47'00"	82°00'00"	85
67	43°46'30"	81°55'00"	46
S	43°45'30"	81°49'30"	20
T	43°45'15"	81°46'45"	13

Table 2. Chemical and Physical Data for Lake Huron, 1956
[For station locations see Table 1 and Figure 1]

Cruise and station	Month and day	Time (EST)	Depth (meters)	Temper- ature (°C)	Na+ (ppm)	K+ (ppm)	Ca++ (ppm)	Cl- (ppm)	SO ₄ ⁼ (ppm)	SiO ₂ (ppm)	Specific conductance (K1gx10 ⁶)	Dissolved oxygen (ppm)	pH
Cruise I													
62	June 5	1700	0	9.0	2.51	0.79	27.0	5.8	11	2.0	174	11.5	7.9
			15	6.9	2.38	0.78	27.5	5.5	12	2.3	170	11.9	7.9
			30	6.7	2.26	0.85	27.0	5.6	11	2.1	169	11.9	7.9
A	June 5	1645	0	8.5	2.56	0.81	28.7	5.1	14	2.3	179	...	...
B	June 5	1615	0	6.7	2.49	0.81	27.4	5.3	14	2.4	176	...	...
C	June 5	1545	0	5.5	2.34	0.87	28.2	4.8	15	2.3	170	...	...
D	June 5	1515	0	4.9	2.46	0.90	27.4	5.5	20	2.3	172	...	...
63	June 5	1350	0	4.5	2.66	0.85	27.6	4.3	12	2.4	171	12.7	7.9
			15	4.2	2.87	0.98	29.1	4.7	19	2.5	176	12.7	7.9
			30	4.2	2.42	0.75	29.2	4.7	7	2.3	172	12.4	7.7
			60	4.0	2.59	0.76	28.2	5.0	12	2.3	171	12.7	7.7
E	June 5	1305	0	5.0	2.82	0.79	28.2	6.0	11	2.5	177	...	...
F	June 5	1235	0	5.6	2.74	0.89	29.8	6.0	13	2.6	179	...	...
G	June 5	1205	0	6.0	2.59	0.82	29.7	4.4	13	2.2	173	...	...
64	June 5	1117	0	6.2	2.86	0.87	29.8	5.5	13	2.6	181	12.3	8.1
			15	5.6	2.53	0.73	28.2	5.1	15	2.2	172	12.4	8.1
			30	5.5	2.66	0.82	28.2	5.9	17	2.2	176	12.3	8.0
H	June 5	1053	0	10.4	4.42	1.06	30.2	12.6	14	1.8	198	...	...
J	June 5	1033	0	11.2	4.28	1.06	32.0	13.9	16	1.4	206	...	...

Table 2. Continued

Cruise and station	Month and day	Time (EST)	Depth (meters)	Temperature (°C)	Na+ (ppm)	K+ (ppm)	Ca++ (ppm)	Cl ⁻ (ppm)	SO ₄ ⁼ (ppm)	SiO ₂ (ppm)	Specific conductance (K ₁₈ ×10 ⁶)	Dissolved oxygen (ppm)	pH
Cruise II													
62	June 21	0922	0	17.4	4.94	1.35	31.6	22.0	14	1.7	236	9.1	8.1
			15	8.1	2.37	0.73	25.8	6.0	11	2.1	178	12.1	8.1
			30	5.7	2.46	0.78	26.4	5.3	13	2.5	178	11.7	7.9
A	June 21	1015	0	16.3	3.78	0.96	27.7	10.2	13	1.8	194	...	...
B	June 21	1045	0	15.8	...	...	...	...	...	...	...	...	...
C	June 21	1115	0	16.5	4.56	1.23	31.1	14.8	19	1.6	220	...	...
D	June 21	1145	0	16.5	...	...	...	...	...	...	...	...	...
63	June 21	1224	0	13.0	2.26	0.69	25.2	5.0	10	1.9	172	10.7	8.1
			15	5.2	2.47	0.81	26.3	5.5	13	2.3	176	13.0	8.1
			30	4.2	2.47	0.79	27.4	6.0	14	2.3	176	12.7	7.9
			60	4.1	2.35	0.75	26.3	5.7	13	2.4	170	12.2	7.9
E	June 21	1315	0	13.6	...	...	...	...	...	...	...	...	...
F	June 21	1345	0	14.0	...	...	...	...	...	...	...	...	...
G	June 21	1415	0	14.2	3.62	1.01	28.3	10.6	12	1.7	194	...	...
64	June 21	1503	0	9.0	2.69	0.86	26.4	6.3	13	1.7	177	11.8	8.1
			15	5.2	2.36	0.80	26.8	5.4	12	2.3	174	12.5	8.1
			30	4.8	2.34	0.79	26.4	6.0	13	2.3	174	12.0	7.9
H	June 21	1540	0	9.6	2.67	0.95	27.1	6.7	13	3.5	177	...	...
J	June 21	1602	0	9.4	2.63	0.82	27.5	7.1	21	2.0	178	...	...
K	June 22	0804	0	8.2	2.55	0.89	25.7	6.8	13	2.0	174	...	...
L	June 22	0829	0	12.0	3.40	1.02	28.6	9.4	11	1.7	190	...	...
65	June 22	0845	0	13.4	3.26	0.94	28.1	9.6	13	1.6	188	10.8	8.1
			15	5.8	2.39	0.87	26.3	5.8	9	2.0	174	12.7	8.1
			30	4.3	2.33	0.85	26.0	6.3	10	2.1	174	12.6	7.9
			43	4.2	2.45	0.91	26.6	5.2	13	2.3	177	12.2	7.9
M	June 22	0940	0	17.0	4.26	1.05	28.3	13.2	13	1.5	203	...	...
N	June 22	1010	0	14.0	2.99	0.85	26.6	7.7	18	1.8	182	...	...
P	June 22	1040	0	12.8	2.68	0.80	26.0	6.0	15	1.8	174	...	...
66	June 22	1120	0	7.7	2.30	0.83	27.7	5.3	13	2.0	172	12.5	8.1
			15	4.7	2.43	0.86	27.2	5.5	14	2.2	176	12.9	8.1
			30	4.1	2.38	0.81	26.0	5.4	13	2.0	171	12.8	8.1
			60	4.0	2.35	0.71	26.4	5.1	13	2.2	171	12.7	8.1
			87	...	2.36	0.76	25.6	5.7	14	2.2	170	12.6	7.9
67	June 22	1210	0	11.7	2.41	0.84	25.0	5.4	15	1.8	173	...	...
			15	11.8	2.44	0.84	25.4	5.9	11	2.0	176	11.2	8.1
			30	6.1	2.37	0.74	24.8	5.3	12	2.1	173	12.5	8.1
			43	5.5	2.51	0.82	26.4	6.0	13	2.7	176	12.7	8.1
				4.3	2.46	0.80	24.5	5.7	15	2.6	172	12.2	7.9
S	June 22	1345	0	14.2	2.53	0.76	26.5	6.0	15	1.8	178	...	...
T	June 22	1359	0	17.1	2.59	0.81	29.2	5.7	16	1.7	187	...	...
Cruise III													
62	July 13	0941	0	16.1	2.55	0.83	28.4	7.2	14	1.7	181	9.5	8.3
			15	10.2	2.61	0.92	27.4	6.8	12	1.9	178	11.0	8.3
			30	5.3	2.37	0.80	27.9	6.6	10	2.7	176	11.3	7.9
A	July 13	1045	0	16.0	2.76	0.98	27.5	6.6	14	1.8	180	...	...
B	July 13	1115	0	15.6	2.48	0.91	26.5	4.7	21	1.7	175	...	...
C	July 13	1145	0	15.2	2.22	0.78	25.8	4.8	11	1.7	168	...	...
D	July 13	1216	0	15.3	2.61	1.08	26.8	5.4	10	1.7	170	...	...
63	July 13	1254	0	14.8	2.21	0.85	25.6	5.5	10	1.9	170	10.0	8.3
			15	12.7	2.46	0.86	27.8	5.2	9	2.2	172	10.7	8.3
			30	4.2	2.34	0.85	26.7	5.4	13	2.1	170	12.8	8.1
			56	4.1	2.47	0.89	27.7	6.0	13	2.6	176	11.8	7.9
E	July 13	1400	0	14.9	2.27	0.89	26.2	4.7	10	1.8	168	...	...
F	July 13	1430	0	15.3	2.43	0.90	27.4	5.0	9	1.8	170	...	...
G	July 13	1500	0	15.8	2.78	0.83	28.1	5.6	11	1.8	180	...	...
64	July 13	1536	0	17.7	4.57	1.30	32.7	14.2	18	1.4	208	9.3	8.3
			15	13.6	2.62	0.94	27.6	6.1	15	1.9	178	10.2	8.3
			30	5.5	2.28	0.88	27.0	5.0	10	2.5	171	11.8	8.1
H	July 13	1630	0	17.3	4.03	1.30	31.0	12.1	16	1.8	198	...	...
J	July 13	1650	0	16.7	3.21	1.03	28.4	8.7	14	1.7	186	...	...

Table 2. Continued

Cruise and station	Month and day	Time (EST)	Depth (meters)	Temperature (°C)	Na+ (ppm)	K+ (ppm)	Ca++ (ppm)	Cl- (ppm)	SO ₄ ⁼ (ppm)	SiO ₂ (ppm)	Specific conductance (K ₁₈ ×10 ⁶)	Dissolved oxygen (ppm)	pH
Cruise IV													
62	Aug. 2	0938	6	17.5	2.29	0.80	27.4	5.1	14	2.0	170	9.4	7.9
			15	16.2	2.28	0.80	25.9	5.0	9	1.7	169	9.7	7.9
			30	10.7	2.35	0.89	26.6	5.1	11	2.0	172	11.6	7.8
A	Aug. 2	1042	6	18.0	2.35	0.87	26.6	5.4	13	1.8	170	...	...
B	Aug. 2	1102	6	19.5	3.56	1.10	29.4	9.6	14	1.4	193	...	...
C	Aug. 2	1142	0	19.7	4.05	1.09	28.2	11.1	13	1.5	196	...	...
D	Aug. 2	1212	0	19.0	3.46	1.07	28.3	7.8	15	1.8	191	...	...
63	Aug. 2	1253	0	19.0	2.73	0.89	26.8	6.1	10	1.5	180	9.1	7.9
			15	16.6	2.51	0.87	27.7	5.1	11	1.6	170	9.6	7.9
			30	4.3	2.33	0.84	25.1	5.4	12	2.6	170	12.6	7.6
			56	4.2	2.26	0.87	26.7	5.3	10	3.9	170	12.4	7.5
E	Aug. 2	1355	0	18.5	2.41	0.82	26.6	6.0	9	1.8	172	...	...
F	Aug. 2	1425	0	19.3	2.86	0.88	26.4	12.9	8	1.8	183	...	...
G	Aug. 2	1455	0	18.6	2.80	0.96	27.8	6.9	8	1.8	181	...	...
64	Aug. 2	1526	0	19.4	3.31	0.99	27.2	11.8	13	1.6	186	9.1	8.2
			15	12.7	2.70	0.85	27.1	7.0	9	1.9	178	9.1	8.0
			30	6.5	2.40	0.90	24.6	5.6	14	2.5	174	11.6	7.7
H	Aug. 2	1618	0	19.3	3.03	0.89	27.2	7.5	16	1.8	182	...	...
J	Aug. 2	1636	0	19.7	3.11	0.96	27.5	8.3	13	1.7	181	...	...
K	Aug. 3	0811	0	19.2	3.23	0.95	25.8	7.9	11	1.8	183	...	...
L	Aug. 3	0822	0	19.1	2.95	0.98	28.3	14.8	14	1.7	180	...	...
65	Aug. 3	0834	0	19.0	2.98	0.98	27.2	7.6	10	1.6	181	9.2	7.9
			15	13.7	2.65	0.93	26.4	6.3	10	1.8	176	10.8	7.9
			30	5.4	2.26	0.85	27.4	5.4	10	2.5	170	11.9	7.6
			42	4.8	2.50	0.91	26.7	5.4	13	2.6	173	11.7	7.5
M	Aug. 3	0950	0	18.7	2.40	0.91	27.8	6.2	10	1.7	175	...	...
N	Aug. 3	1020	0	18.9	2.70	0.94	27.3	6.3	11	1.5	177	...	...
P	Aug. 3	1050	0	18.8	2.94	0.91	27.8	7.3	11	1.5	181	...	...
66	Aug. 3	1122	0	19.3	2.84	0.90	26.3	7.9	10	1.4	181	9.1	8.1
			15	15.2	2.51	0.87	25.8	6.7	13	1.7	173	10.4	8.1
			30	5.2	2.36	0.75	27.2	5.7	11	1.8	170	13.5	8.0
			60	4.1	2.42	0.86	26.5	5.5	14	2.2	172	12.0	7.6
			85	4.0	2.38	0.75	25.3	6.0	12	2.8	171	11.7	7.5
R	Aug. 3	1305	0	18.7	2.47	0.76	28.3	6.3	15	1.6	176	...	...
67	Aug. 3	1331	0	19.7	2.75	0.79	28.6	7.3	10	1.4	178	9.1	8.1
			15	6.2	2.60	0.91	26.8	5.3	18	1.8	172	14.1	8.1
			30	4.2	2.54	0.73	27.8	4.9	15	2.3	176	12.7	7.9
			42	4.2	2.46	0.76	27.6	5.1	11	2.5	171	12.5	7.9
S	Aug. 3	1427	0	18.2	2.62	0.87	27.4	5.7	13	1.6	176	...	...
T	Aug. 3	1441	0	14.5	2.79	0.93	28.0	11.2	14	2.0	182	...	...
Cruise V													
62	Aug. 24	1026	0	18.1	2.38	0.83	26.9	5.4	11	1.9	173	9.1	8.2
			15	18.0	2.33	0.83	26.2	4.9	14	1.6	171	9.1	8.2
			30	9.5	2.31	0.76	27.3	5.3	14	2.4	171	11.0	7.9
A	Aug. 24	1136	0	17.5	2.34	0.81	27.5	4.9	14	1.7	166	...	...
B	Aug. 24	1207	0	18.0	2.79	0.90	27.8	7.6	13	1.5	172	...	...
C	Aug. 24	1236	0	18.2	3.09	0.88	27.3	7.8	10	1.6	181	...	...
63	Aug. 24	1348	0	16.9	2.33	0.79	26.1	5.7	14	1.6	166	9.5	7.9
			15	16.7	2.32	0.78	26.7	5.0	13	1.6	167	9.5	7.9
			30	4.6	2.45	0.80	26.6	5.3	14	2.3	171	12.2	7.9
			53	4.5	2.45	0.81	25.8	5.1	12	2.3	168	12.1	7.6
E	Aug. 24	1450	0	17.3	2.46	1.08	28.0	6.0	12	1.6	173	...	...
F	Aug. 24	1520	0	18.4	3.04	1.01	25.7	7.7	15	1.4	176	...	...
G	Aug. 24	1550	0	18.6	2.97	1.02	26.2	8.1	15	1.8	175	...	...
64	Aug. 24	1623	0	19.1	3.09	1.01	28.0	8.0	13	1.4	180	8.9	8.1
			15	18.4	2.99	0.99	27.7	8.0	13	1.3	179	9.1	8.1
			28	12.1	2.40	0.87	26.1	5.0	14	1.7	168	11.1	8.1
H	Aug. 24	1719	0	19.4	4.26	1.19	28.1	12.7	17	1.6	198	...	...
J	Aug. 24	1738	0	19.7	4.11	1.11	28.0	12.0	17	1.7	197	...	...

Table 2. Continued

Cruise and station	Month and day	Time (EST)	Depth (meters)	Temperature (°C)	Na+ (ppm)	K+ (ppm)	Ca++ (ppm)	Cl- (ppm)	SO ₄ ⁼ (ppm)	SiO ₂ (ppm)	Specific conductance (K ₁₆ ×10 ⁵)	Dissolved oxygen (ppm)	pH
Cruise VI													
62	Sept. 13	0911	0	17.5	2.65	0.74	25.3	5.6	13	1.7	172	9.1	8.1
			15	15.5	2.60	0.77	25.8	5.1	12	1.7	174	9.4	8.1
			30	7.7	2.43	0.68	26.2	4.7	10	2.6	171	11.0	7.6
A	Sept. 13	1010	0	17.8	2.51	0.70	25.0	4.9	10	1.8	167	...	...
B	Sept. 13	1040	0	17.7	2.49	0.66	24.9	5.1	14	2.2	171	...	...
C	Sept. 13	1110	0	17.6	2.31	0.78	25.9	4.9	14	2.0	167	...	...
D	Sept. 13	1140	0	17.4	2.26	0.78	25.7	4.6	13	1.9	166	...	...
63	Sept. 13	1222	0	17.4	2.30	0.80	26.1	5.1	10	1.9	170	9.1	8.2
			15	17.0	2.37	0.80	25.4	5.3	10	1.9	175	9.0	8.2
			30	4.3	2.33	0.77	24.9	4.7	8	2.6	171	11.5	7.6
			55	4.2	2.29	0.83	25.3	4.4	13	3.8	173	11.4	7.6
E	Sept. 13	1320	0	17.4	2.31	0.88	26.2	4.3	9	1.8	168	...	...
F	Sept. 13	1350	0	17.8	2.90	0.91	26.7	7.5	14	1.8	179	...	...
G	Sept. 13	1420	0	17.9	2.84	0.92	26.4	7.0	10	1.7	179	...	...
64	Sept. 13	1506	0	18.1	3.04	0.93	26.0	7.4	13	1.9	179	8.9	8.1
			15	17.7	2.70	0.85	26.6	6.4	14	1.7	179	8.6	8.1
			30	5.6	2.32	0.78	25.5	5.1	14	3.1	171	10.3	7.7
H	Sept. 13	1605	0	18.0	2.83	0.91	28.2	6.6	14	2.2	181	...	...
J	Sept. 13	1624	0	17.9	3.01	0.92	27.2	7.1	15	2.0	182	...	...
K	Sept. 15	0808	0	16.9	2.50	0.92	27.9	7.3	13	1.9	183	...	...
L	Sept. 15	0815	0	17.4	2.75	0.98	26.6	6.6	13	1.8	179	...	...
65	Sept. 15	0836	0	17.7	2.65	0.93	26.7	6.4	14	1.6	178	8.9	8.2
			15	17.7	2.82	0.93	25.5	6.7	13	1.7	174	8.5	8.2
			30	6.5	2.87	0.86	27.2	5.4	13	2.5	171	10.0	7.7
			42	6.2	2.30	0.95	26.8	5.1	11	2.7	172	9.5	7.6
M	Sept. 15	1005	0	17.7	2.59	0.90	26.8	6.7	10	1.7	179	...	...
N	Sept. 15	1035	0	17.7	2.54	0.85	25.5	5.9	13	1.5	174	...	...
P	Sept. 15	1105	0	17.1	2.50	0.79	25.4	5.3	13	1.7	174	...	...
66	Sept. 15	1148	0	17.9	2.49	0.91	25.0	5.8	10	1.7	176	8.7	8.2
			15	12.9	2.50	0.93	25.8	5.9	10	1.6	175	8.0	8.2
			30	5.6	2.31	0.95	26.6	5.3	9	2.1	171	10.6	7.9
			60	4.3	2.28	0.91	26.4	5.4	10	2.5	170	9.5	7.5
			85	4.2	2.27	0.91	26.4	5.4	11	2.5	171	9.6	7.5
R	Sept. 15	1305	0	18.0	2.67	0.97	26.8	6.1	13	1.6	175	...	...
67	Sept. 15	1325	0	17.8	2.62	0.93	26.0	6.8	12	1.7	176	8.5	8.2
			15	17.9	2.69	0.82	26.1	6.8	10	1.7	177	8.4	8.2
			30	5.4	2.49	0.85	24.7	5.8	11	2.6	171	11.0	7.5
			42	5.0	2.36	0.83	25.2	5.3	8	2.7	170	10.9	7.5
S	Sept. 15	1407	0	17.8	2.56	0.85	25.6	6.4	13	1.8	177	...	...
T	Sept. 15	1421	0	18.0	2.68	0.89	26.4	6.8	14	1.9	180	...	...
Cruise VII													
62	Oct. 5	0923	0	13.2	2.47	0.84	27.6	5.6	12	1.9	175	10.0	8.1
			15	13.2	2.22	0.77	26.5	5.4	10	1.7	167	10.0	8.1
			30	13.2	2.22	0.73	26.4	5.9	13	1.8	166	9.8	8.0
A	Oct. 5	1043	0	13.0	2.46	0.78	25.6	5.9	13	2.1	171	...	...
B	Oct. 5	1113	0	12.5	2.34	0.81	27.4	5.7	13	1.7	171	...	...
C	Oct. 5	1143	0	12.3	2.20	0.72	26.2	5.7	10	1.6	164	...	...
D	Oct. 5	1213	0	12.8	2.97	0.88	31.2	6.4	15	2.0	199	...	...
63	Oct. 5	1252	0	13.0	2.50	0.72	28.3	6.1	8	1.7	174	10.2	8.0
			15	12.9	2.57	0.76	26.6	6.3	13	1.8	167	10.2	8.0
			30	11.3	2.54	0.75	25.7	5.9	13	1.9	168	10.4	7.9
			54	4.8	2.40	0.74	26.8	5.5	10	2.9	170	11.5	7.4
E	Oct. 5	1406	0	13.0	2.49	0.78	26.8	5.9	13	1.7	170	...	...
F	Oct. 5	1436	0	13.6	2.63	0.89	28.7	7.1	14	1.8	180	...	...
G	Oct. 5	1506	0	13.9	2.76	0.81	29.2	6.9	13	1.9	188	...	...
64	Oct. 5	1548	0	13.6	2.67	0.81	26.7	6.4	14	1.8	173	9.9	7.8
			15	13.4	2.55	0.79	26.2	6.5	11	1.7	173	10.0	7.8
			30	9.1	2.68	0.86	27.3	5.7	11	2.6	176	10.2	7.7
H	Oct. 5	1652	0	14.1	2.68	0.82	28.6	6.9	10	2.2	181	...	...
J	Oct. 5	1711	0	14.0	2.71	0.83	28.7	6.9	13	1.8	178	...	...

Table 2. Continued

Cruise and station	Month and day	Time (EST)	Depth (meters)	Temperature (°C)	Na+ (ppm)	K+ (ppm)	Ca++ (ppm)	Cl ⁻ (ppm)	SO ₄ ⁼ (ppm)	SiO ₂ (ppm)	Specific conductance (K ₁₈ ×10 ⁶)	Dissolved oxygen (ppm)	pH
Cruise VIII													
62	Oct. 27	0921	0	11.3	3.95	1.03	27.0	11.8	15	2.0	197	9.6	8.0
			15	11.3	3.78	0.99	27.0	10.5	11	2.0	195	9.6	8.0
			30	11.2	3.77	0.91	26.8	10.8	15	1.8	194	9.7	8.0
A	Oct. 27	1019	0	10.5	2.73	0.78	25.0	6.3	14	2.1	177	...	...
B	Oct. 27	1049	0	10.5	2.49	0.72	24.5	6.0	13	2.1	171	...	...
C	Oct. 27	1119	0	10.7	2.54	0.73	26.9	5.7	13	2.0	176	...	...
D	Oct. 27	1149	0	10.2	2.37	0.74	26.4	5.2	12	2.2	172	...	...
63	Oct. 27	1231	0	11.1	2.51	0.73	27.0	6.1	11	2.1	172	9.4	7.8
			15	10.9	2.50	0.74	26.7	6.1	13	2.2	173	9.9	7.8
			30	10.6	2.59	0.80	27.5	6.3	15	2.0	172	9.4	7.8
			59	7.0	2.35	0.82	25.4	5.9	10	2.6	171	10.0	7.4
E	Oct. 27	1400	0	10.6	2.59	0.79	26.9	6.0	15	2.1	175	...	...
F	Oct. 27	1430	0	8.6	2.44	0.78	27.5	6.3	12	2.3	174	...	...
G	Oct. 27	1500	0	10.2	2.62	0.96	28.2	6.4	16	2.1	183	...	...
64	Oct. 27	1540	0	9.3	2.56	0.89	26.6	7.0	13	2.3	172	10.1	7.8
			15	8.7	2.56	0.84	26.3	6.0	14	2.4	173	10.2	7.8
			30	6.9	2.42	0.85	26.4	5.2	11	2.6	172	10.5	7.6
H	Oct. 27	1637	0	9.8	2.63	0.86	28.4	5.7	16	2.5	178	...	...
J	Oct. 27	1655	0	10.4	2.78	0.92	24.8	6.2	15	2.2	177	...	...
K	Oct. 27	1717	0	10.4	2.57	0.85	25.8	5.3	14	2.3	175	...	...
L	Oct. 27	1728	0	11.6	2.51	0.76	22.9	6.2	14	2.0	173	...	...
65	Oct. 27	1740	0	12.0	2.60	0.82	24.4	7.0	14	1.9	171	9.7	8.2
			15	11.8	2.60	0.79	27.5	6.5	10	1.9	177	9.4	8.2
			30	6.5	2.46	0.78	26.2	5.4	8	2.6	171	10.3	7.9
			42	6.2	2.21	0.82	25.9	6.0	9	2.5	171	9.9	7.9
M	Oct. 27	1855	0	12.0	2.52	0.83	26.3	5.6	13	1.7	173	...	...
N	Oct. 27	1925	0	11.6	2.59	0.83	26.8	6.0	12	1.6	170	...	...
P	Oct. 27	1955	0	11.5	2.68	0.91	25.6	5.8	12	1.7	178	...	...
66	Oct. 27	2018	0	11.4	2.44	0.82	26.5	4.9	17	1.6	174	9.5	8.2
			15	11.2	2.54	0.90	25.8	5.7	14	1.7	171	9.4	8.2
			30	11.1	2.48	0.85	26.6	6.5	13	1.9	176	9.1	8.1
			60	5.4	2.37	0.78	26.0	5.5	13	2.3	174	10.4	7.8
			90	4.7	2.47	0.86	29.2	4.9	14	2.4	175	10.9	7.7
R	Oct. 27	2145	0	11.4	2.52	0.81	34.8	5.0	13	1.8	171	...	...
67	Oct. 27	2207	0	11.2	2.79	0.88	26.4	5.7	13	1.7	181	9.8	8.1
			15	11.0	2.48	0.77	24.5	5.6	12	1.7	170	9.9	8.1
			30	10.4	2.40	0.77	25.8	5.2	13	1.7	174	9.2	8.0
			42	8.2	2.47	0.82	26.2	5.4	8	2.1	177	9.9	8.0
S	Oct. 27	2256	0	9.6	2.45	0.84	25.9	5.5	14	1.9	171	...	...
T	Oct. 27	2309	0	9.6	2.69	0.89	27.8	6.1	15	1.9	181	...	...

The median values for all chemicals, with the exception of silica, were higher at the lake surface than in subsurface samples. This difference between surface and subsurface was slight and usually was less than the analytical reliability for any pair of observations. Silica concentrations were higher in the subsurface samples for which the median value was 2.2 ppm as compared with the median surface value of 1.8 ppm. The major cause of silica depletion from the water is its incorporation by diatoms. Diatom populations fluctuate seasonally and are more abundant in warmer than colder waters. Medians were 1.8 ppm for the epilimnion and 2.4 ppm for the hypolimnion. The median surface silica concentration was 2.1 ppm for the first and last cruises and 1.7 ppm for cruises II through VIII. Concentrations did not fluctuate seasonally for any other ion.

Concentrations much higher than the medians were obtained most frequently for sodium, calcium, chloride, and conductivity. These higher values were due to outflow of water from Saginaw Bay.

The current pattern which Johnson (1958) construed from recoveries by drift bottles released during cruises I, III, and IV (Fig. 1) is substantiated by chemical analyses which show very high concentrations at stations 64, J, and K. Saginaw Bay water was flowing out of the bay during these cruises and continuing along the western shore of the lake. Drift-bottle returns for cruise V did not, however, indicate a current along this shore but chemical analyses indicated the presence of water from Saginaw Bay.



Fig. 2. Surface currents during cruise II. Dashed line represents the usual Lake Huron current and heavy line indicates the Saginaw Bay current based on drift-bottle data from Johnson (1958); squares show the release points and X's the recovery points of bottles.

The drift-bottle returns from cruise II indicated a current which extended much farther into the lake (Fig. 2) than did the currents during cruise I. Chemical analyses showed water of Saginaw Bay origin to be present at stations 62 through C and stations L, 65, and M. Saginaw Bay water also appeared at station G.

The chemical analyses showed Saginaw Bay water at no station during cruise VII and only at station 62 during cruise VIII. The current pattern for these cruises (Fig. 3) indicated that the flow from Saginaw Bay was north instead of south as is usual. The bay water did not flow through the transects where water samples were taken.

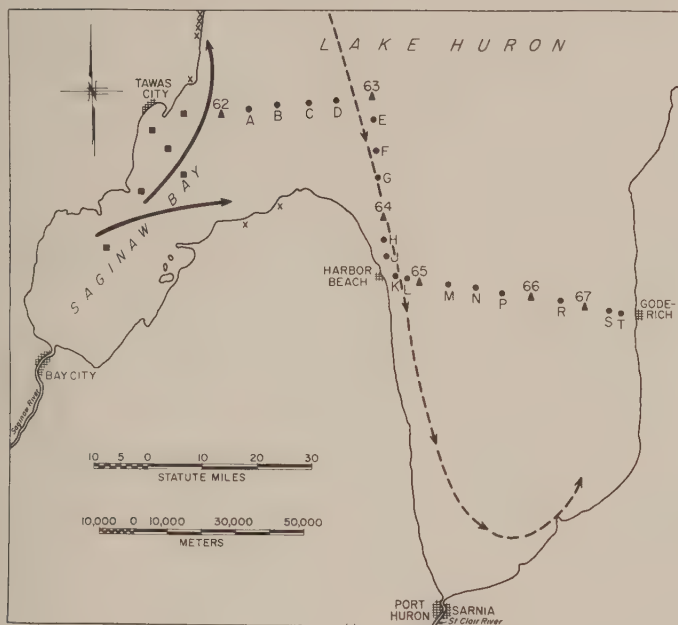


Fig. 3. Surface currents during cruise VII. Dashed line represents the usual Lake Huron current and heavy line indicates the Saginaw Bay current based on drift-bottle data from Johnson (1958); squares show the release points and X's the recovery points of bottles.

Because many bays and rivers of high chemical content discharge into the Great Lakes, care must be taken in sampling in the vicinity of these outflows. A knowledge of currents makes it possible to evaluate properly samples taken in areas where the mixing of waters is incomplete. Prejudice of results can thus be avoided.

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at latitude 52°52'N. and longitude 167°07'W. This sample was collected on July 12, later than the peak of the runs in Bristol Bay streams, and may have consisted in all or part of stocks from other North American areas, possibly Alaska Peninsula or Aleutian Island streams.

CLASSIFICATION OF BERING SEA SAMPLES

Sample numbers 34 and 37 at longitude 177°07'W. and latitude 54°01'N. and longitude 175°57'W. and latitude 53°28'N., respectively, consisted predominantly of Bristol Bay type salmon. Sample 37, with only 33 fish, had a large confidence interval, 39 to 99 per cent, and the interval for sample 34, with 65 specimens, was 82 to 100 per cent.

SUMMARY AND CONCLUSIONS

During May to July of 1962, sockeye salmon were collected in the North Pacific Ocean and Bering Sea for morphological studies. Samples of less than 30 specimens were excluded. This left 39 samples for determining distributions of continental stocks on the high seas in 1962, of which 37 were collected in the North Pacific Ocean, all but one west of longitude 175°W. Two samples were collected in the Bering Sea west of longitude 175°W.

Two obvious sampling problems hindered the analysis. One was the absence of samples from or near the sockeye salmon producing areas of the Kamchatka Peninsula for use as estimators of the Kamchatkan errors of misclassification. The best samples available and used for this purpose were collected in June several hundred miles off the southeastern coast of Kamchatka. Presence of maturing Bristol Bay salmon in abundance in this area is unlikely. The second sampling problem was that paucity of samples severely limited determination of the general high seas distribution of continental stocks, except in one rather restricted zone of the North Pacific Ocean.

The incidence of Bristol Bay type sockeye salmon increased eastward from longitude 175°E., predominating in the majority of the samples. Variability among samples indicated some intermingling of continental stocks or the inclusion of local stocks from areas other than Bristol Bay or Kamchatka. West of longitude 175°E. Kamchatka sockeye salmon dominated in all but three samples. The other samples classified as 0-24 per cent Bristol Bay type salmon.

On the basis of the available samples taken in 1962, the high seas distribution of maturing Bristol Bay and Kamchatkan sockeye salmon in the North Pacific

Ocean and Bering Sea was quite consistent with results of previous years.

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ANALYSIS OF SCALE CHARACTERS

Morphological, serological and tagging results have defined in various degrees the distribution and intermingling of salmon stocks originating in North America and Asia. Scale characters are now supplanting meristic characters in defining areas of origin. Scales are economical to collect, convenient to process and easy to exchange with other fishery agencies.

Present procedures begin with collection of a scale sample from a specified body area, and preferably with selection of a particular scale from within that area (p. 115, Annual Report 1961, INPFC). Careful counts of circuli and measurements of growth zones are next made in the laboratory from plastic impressions of the scales. Useful data are then selected by statistical tests. Determination of the area of origin follows from analyses of the frequency distributions of one, two, or several scale characters.

Research on pink and sockeye salmon scales is reported here; the section entitled "Chum Salmon Morphology Studies" given progress on chum salmon. Investigation of chinook and coho salmon scales and sockeye in the Gulf of Alaska, preliminary at this time, are not reported.

SOCKEYE SALMON SCALE STUDIES

by Raymond E. Anas

Scales of sockeye salmon have been used to determine continental origins and areas of intermingling of this species in the North Pacific Ocean and in the

Bering Sea. Progress has been reported in the annual reports of the International North Pacific Fisheries Commission from 1956 to 1961. Information gained from past studies indicated that a better basic knowledge of the use of scales for determining the continental origin of fish caught at sea was needed. Reported here are the results of the following investigations: (1) Study of factors that could cause variation of the basic data within races of sockeye salmon; (2) Study of the stability of scale characters to determine their efficiency.

STUDY OF VARIATION

If the results of classifying high seas samples to continent of origin are affected by factors that cause scale characters to vary within populations, then knowledge should be gained of this variation. Before sources of variation can be investigated, however, basic scale data must be selected. The first step in selecting basic data for this study was the determination of the continental spawning areas of fish caught at sea. Fukuhara *et al.* (1962) show that sockeye salmon caught in the Bering Sea and western Aleutian areas are principally from Bristol Bay in North America and from West Kamchatka in Asia. Basic scale data were chosen that would differentiate Bristol Bay fish from Okhotsk Sea fish. Samples from the Okhotsk Sea were used because samples from Asian rivers were not available. Scale characters selected for study and the results of some of the earlier tests were described in Anas (1962)¹. Table 25 of the present report gives only those characters that best separate Bristol Bay from Okhotsk Sea sockeye.

Three possible sources of error were studied: (1) variation resulting from the particular axis chosen for counting and measuring scale characters, (2) factors associated with the biology of the species, and (3) correlation between pairs of scale characters, and between body length and scale characters. Tests of body location where a scale is taken and of scale readers were reported in Anas (1962).

Scale Axis

Eleven methods of selecting a scale axis were compared to determine the method with the smallest variation of repeated trials. The method that resulted in the least variation was: (1) visual determination of the longest radius of the scale, and (2) visual bisection of the freshwater zone using the longest radius for

orientation. The 95 per cent confidence limits of the observed values determined by this method were plus or minus 10 degrees, and the average deviation was less than one degree. One scale character (16 in Table 25) was dropped after these tests.

Biological Factors

Samples were tested for differences due to sex or sampling date. Scale characters having significant differences (characters 1 and 3 in Table 25) between means for these tests were dropped from further study. Plus growth was examined. All of the scale characters that remained after the tests of scale axis, sex and sampling date in Table 25 were independent of plus growth.

Tests of brood years, freshwater ages and ocean ages were included in the category of factors on which the environment could have had a significant effect. For instance, tests of brood years include fish that spent different years in fresh water and ocean environments. There is no way at this time to differentiate between the variation due to genetic differences between brood years and differences caused by the environment. Since significant brood year differences occurred for all the scale characters tested, it is necessary each year to test the percentage of each age group misclassified before sockeye salmon caught at sea are classified to continent of origin. Samples of known origin should be used for these tests.

Correlation

Test of the correlation between pairs of scale characters are necessary because the amount of correlation between paired characters must be subtracted before the second character can be used for racial studies. Highly correlated characters should be avoided. Six scale characters remained for further study after these tests (numbers 2, 4, 7, 9, 14 and 15 in Table 25).

Tests of the correlation between body length and each of the scale characters are necessary because certain types and sizes of fishing gear will select fish by length. This could cause errors in the classification of fish caught at sea. The portion of the total variance of any scale character attributable to the variation in length was always less than two per cent, and in most cases it was less than one per cent. It was concluded, therefore, that body length could be ignored as a source of variation for the six scale characters studied.

STUDY OF STABILITY

Scale characters are defined here as being stable if there is minimum overlap of the frequency curves

¹ Additional tests this year changed and corrected some of the data in Table 20 of Anas (1962). In column 3, change (+) to (-) for characters FWC/OC₁C and Int 6+7. In column 4, change (-) to (+) for character 1st 1/2 (c). In column 7, change (+) to (-) for character Int 1+2.

TABLE 25. Summarization of tests of sources of variation, 1956-1960.

No.	Scale character ²⁾	Sources of variation ¹⁾						
		Scale axis	Sex	Sampling date	Brood year	Freshwater age	Ocean age	Plus growth
1	1st 1/6(C)	NS	I					
2	2nd 1/6(C)	NS	NS	NS	**	**	NS	NS
3	1st 1/3(C)	NS	I					
4	1st 1/2(C)	NS	NS	NS	**	**	I	NS
5	1st 1/6(C)/OC ₁ C	NS	NS	NS	**	**	I	NS
6	1st 1/3(C)/OC ₁ C	NS	NS	NS	**	**	NS	NS
7	3rd 1/3(C)/OC ₁ C	NS	NS	NS	**	NS	NS	NS
8	1st 1/2(C)/OC ₁ C	NS	NS	NS	**	**	I	NS
9	2nd 1/2(C)/OC ₁ C	NS	NS	NS	**	**	I	NS
10	INT. 1	NS	NS	NS	**	**	I	NS
11	INT. 2	NS	NS	NS	**	*	*	NS
12	INT. 6	NS	NS	NS	**	NS	**	NS
13	INT. 7	NS	NS	NS	**	NS	I	NS
14	INT. 1+2	NS	NS	NS	**	**	I	NS
15	INT. 5+6	NS	NS	NS	*	*	NS	NS
16	INT. 6+7	NS	NS	NS				
17	INT. 1+2/5+6+7	NS	NS	NS	**	**	NS	NS

1: Significant interaction

**: Means significantly different at 1 per cent level

*: Means significantly different at 5 per cent level

NS: Means not significantly different

Description of scale characters:

No. 1: Circulus count within the first sixth of the length of the first ocean zone.

No. 2: Circulus count within the second sixth of the length of the first ocean zone.

No. 3: Circulus count within the first third of the length of the first ocean zone.

No. 4: Circulus count within the first half of the length of the first ocean zone.

No. 5: Ratio of the circulus count within the first sixth of the length of the first ocean zone to the total circulus count of the first ocean zone.

No. 6: Ratio of the circulus count within the first third of the length of the first ocean zone to the total circulus count of the first ocean zone.

No. 7: Ratio of the circulus count within the last third of the length of the first ocean zone to the total circulus count of the first ocean zone.

No. 8: Ratio of the circulus count within the first half of the length of the first ocean zone to the total circulus count of the first ocean zone.

No. 9: Ratio of the circulus count within the second half of the length of the first ocean zone to the total circulus count of the first ocean zone.

No. 10: The scale length measured across the first three ocean-type circuli (1-3) using the first ocean-type circulus as a starting point.

No. 11: The scale length measured across circuli 4-6 as in No. 10.

No. 12: The scale length measured across circuli 16-18 as in No. 10.

No. 13: The scale length measured across circuli 19-21 as in No. 10.

No. 14: INT. 1 plus INT. 2

No. 15: INT. 5* plus INT. 6

No. 16: INT. 6 plus INT. 7

No. 17: INT. 1 plus INT. 2 divided by INT. 5* plus INT. 6 plus INT. 7

* INT. 5 is the scale length measured across circuli 13-15 in the first ocean zone.

between standard areas, between and within years. Data collected from 1956 to 1962 were used to evaluate the stability of the characters.

A comparison of means and variances indicated that scale characters 4, 14 and 15 in Table 25 were best for distinguishing Bristol Bay from Okhotsk Sea sockeye in 1957, so these scale characters were used for the comparisons between different years. A discriminant function computed from data collected in 1957 was used to evaluate stability. Figure 31 shows that in 11 years the selected scale characters distinguished Bristol Bay from Asian sockeye. Considerable variability in the percentage misclassified, however, occurred between the different years. Computation of a new function for each year resulted in only slight improvement over the function computed from 1957 data. Samples from eastern Gulf of Alaska inshore areas classify unlike those from Bristol Bay collected in 1957.

Since significant differences between brood years exist for all of the scale characters, it is necessary to check each age group (4_2 , 5_3 , and so on) to determine its stability. The alternatives are to drop certain age groups or to collect enough samples to analyse each age group separately. Since the latter method may not be feasible, pooling of the ages is desirable.

Samples collected from Bristol Bay rivers are best for comparisons of age groups because Asian samples may contain fish from several rivers. The different age groups found in samples collected in 1957 and 1962 were classified to continent of origin. These data

TABLE 26. Classification of sockeye salmon by age group using the 1957 discriminant function and three scale characters [1st 1/2(C), INT. 1+2 and INT. 5+6] for 1957.

Area	Subarea	Age	Sample size	Observed percentage of misclassification
Bristol Bay	Naknek R.	5_2	35	3
	"	6_3	138	5
	Egegik R.	6_3	91	3
	Ugashik R.	4_2	30	3
	"	5_2	63	14
	Kvichak R.	5_2	97	14
	Wood R.	5_2	40	8
Okhotsk Sea	51 E 154 (1)	4_2	28	7
	"	5_2	37	11
	"	5_3	22	9
	"	6_3	70	31
	51 E 154 (2)	5_2	89	9
	"	6_3	32	31
	52 E 154	5_2	65	15
	"	6_3	49	20

TABLE 27. Classification of sockeye salmon by age group using the 1957 discriminant function and three scale characters [1st 1/2(C), INT. 1+2 and INT. 5+6] for 1962.

Area	Subarea	Age	Sample size	Observed percentage of misclassification
Bristol Bay	Naknek R.	5_2	21	14
	"	5_3	33	15
	"	6_3	50	4
	Egegik R.	5_3	118	12
	"	6_3	32	3
	Ugashik R.	5_2	21	24
	"	5_3	121	26
	Kvichak R.	5_3	191	16
	"	6_3	102	7
	Wood R.	4_2	118	43
Southeast Kamchatka	"	5_3	26	27
	Branch R.	4_2	23	17
	"	5_3	41	10
	"	6_3	79	21
	"	6_4	78	35

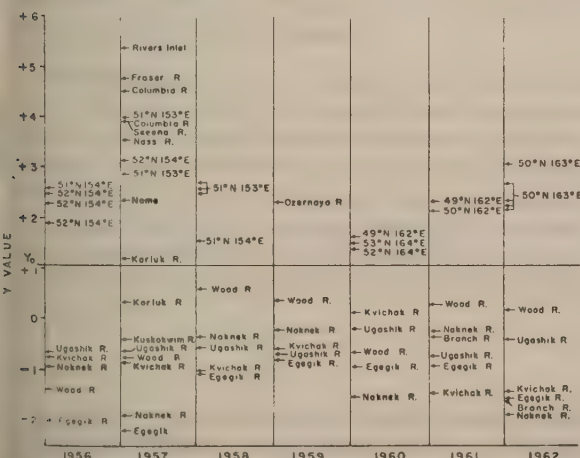


FIGURE 31. Classification of combined ages of sockeye samples collected from 1956-1962 to either western Alaska or Asia using three scale characters (1st 1/2(C), INT. 1+2 and INT. 5+6) with a discriminant function computed from data collected in 1957.

indicate that the differences between age groups for Bristol Bay were greater in 1962 than in 1957 (Tables 26 and 27).

Thirty-five per cent of age 6_4 fish were misclassified for East Kamchatka samples collected on July 9, 11 and 13 in 1962. Elimination of age group 6_4 would improve classification of Asian samples. Since age 6_4 fish apparently were uncommon in Bristol Bay in

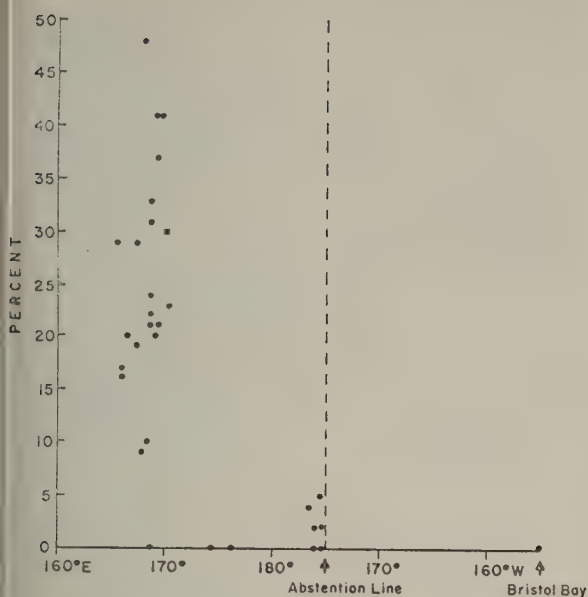


FIGURE 32. Percentages of age group 6_4 mature sockeye salmon in high seas samples collected in July 1962. Sample sizes of 30 or more fish were used.

1962, whereas that age group was common in samples collected off East Kamchatka, substantial numbers of age 6_4 fish would indicate the presence of Asian sockeye salmon. Figure 32 shows percentages of mature age 6_4 sockeye in high seas and Bristol Bay samples collected in 1962. A high percentage of age 6_4 fish occurred around 170° East longitude; one sample with no age 6_4 fish occurred at 168° East longitude. This would indicate either non-representative sampling or a racial composition different from that in other samples collected west of 170° East longitude.

In conclusion, counts of total circuli in the freshwater zone (including plus growth) and selection of characters from within the first ocean zone are recommended for future work. This procedure will render scale characters more useful in solving the problem of identifying the origin of sockeye salmon caught at sea. Also recommended is the collection of scales from body zone "A" above the lateral line (Annual Report 1962, INPFC).

SUMMARY

1. Seventeen scale characters were selected for the purpose of differentiating Bristol Bay from Okhotsk Sea sockeye salmon.

2. Study of factors causing variation in the basic data within races of sockeye salmon resulted in retention of three scale characters.

3. These characters were used to compute a discriminant function. A function based on data collected in 1957 differentiated Bristol Bay from Okhotsk Sea and East Kamchatka sockeye salmon in samples collected from 1956 to 1962. Percentages of fish misclassified differed, however, from year to year.

4. Some heterogeneity between different age groups was expected due to significant differences between brood years for all scale characters. Empirical tests of the data showed more heterogeneity in 1962 than in 1957.

5. The age composition of samples collected at sea is useful for the following reasons: (a) an age group may be eliminated if it does not classify well, and (b) racial identities may be indicated from these data. Samples collected in 1962 indicated that age 6_4 was common in samples of mature sockeye salmon collected near Kamchatka, but uncommon in Bristol Bay. A concentration of age 6_4 fish occurred around 170° East longitude. Some samples with no 6_4 sockeye occurred to 168° East longitude. These could be composed of Asian fish of different racial origin.

6. It is recommended for future studies that the total freshwater circuli (including plus growth) be counted and scale characters from within the first ocean zone be determined. Also, scales should be collected from body zone "A" above the lateral line.

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PINK SALMON SCALE STUDIES

by Roger E. Pearson

Six meristic characters were used to classify pink salmon taken from the Bering Sea and North Pacific Ocean in 1959 to continent of origin (Pearson, 1961). The spawning regions of eastern Kamchatka and western Alaska were assumed to be the destinations of pink salmon taken on the high seas. Consequently, meristic characters taken from eastern Kamchatkan and western Alaskan fish were used to compute continental morphotypes. The resulting classification

FISHES OF SOME SOUTH CAROLINA COASTAL PLAIN STREAMS

WILLIAM D. ANDERSON, JR.

DISTRIBUTION of the freshwater fishes in the Ashepoo, Combahee, Broad, and New River drainages of southeastern South Carolina was studied from 1956 through 1960. These systems are in the coastal plain between Edisto and Savannah River drainages in parts of Allendale, Bamberg, Barnwell, Beaufort, Colleton, Hampton, and Jasper counties. Ashepoo and Combahee drain into St. Helena Sound, Broad drains into Port Royal Sound, and New into Tybee Roads. Drainage areas of the rivers in square miles are: Ashepoo, 385; Combahee, 1,356; Broad, 727; and New, 284; for a total of 2,752 square miles or 1,761,280 acres (communication from Walter M. Bell, Corps of Engineers, Charleston, South Carolina).

The general course of these rivers is to the southeast. For most of their lengths they flow over deposits of Tertiary age, but near their mouths they pass over sands and clays of Pleistocene or Recent age. At the headwaters of the Combahee the topography is somewhat rolling, but becomes flat a few miles southeastward and remains so, for the most part, all the way to the coast.

This region is of considerable interest biologically, as it has a rich flora and fauna and is largely unspoiled by man. Much of the land is in the possession of large land owners who have been good guardians of our natural resources. This furnishes an excellent comparison with areas not so well managed. Productive farms are scattered throughout; and a great portion of the territory is forested, some quite densely, making the pulp and timber industry of great importance. There is little domestic or industrial pollution. The generally level lands lend themselves easily to good soil conservation practices, and as a consequence there is little erosion and almost no silting of streams.

Most of the streams sampled are typical of the types which have their origins and entire courses confined to the South Atlantic coastal plain. They are usually clear and vary in color from that of drinking water (at or near their headwaters) to that of strong tea. The color stems from dissolved organic material. At a few stations (mostly stagnant pools) the water was milky or muddy. Bottom

types encountered include muck, sand, gravel, and organic debris. The bottoms in still areas are mostly muck, but in areas of flowing water the bottoms are generally composed of soft to firm sand. At a few localities the bottom contains considerable gravel. Dead trees, limbs, stumps, and leaves make up an integral part of the bottom of many streams. In most cases, the streams are surrounded by swamps, predominantly gum-cypress, but which possess a great diversity of flora. Aquatic plants are abundant (see Baldwin, 1956, p. 5-12, for a listing of the types of aquatics common to this area).

Ten-foot minnow seines and 20-foot bag seines were used to obtain most specimens. A few collections were made by poisoning with rotenone. Each locality was assigned a station number. Specimens were preserved in the field in 10 percent formalin and were later converted to 38 percent isopropyl alcohol.



Fig. 1. Map of South Carolina with study area crosshatched.

STATIONS

Collections were made from May 30, 1956, to May 25, 1959, mostly during the summers of 1956 and 1957.

Choice of streams seined was limited by ease of access, and by depth of water and width of stream as only 10- and 20-foot seines were used.

The list of stations contains: (1) station number, name of county, locality; (2) drainage; (3) date of collection; and (4) when available, certain environmental data, such as color and clarity of the water, most prominent bottom conditions encountered, and temperature of the water in degrees Fahrenheit at approximately 1 inch below the surface, taken in the shade, where possible.

This study was not primarily ecological in nature, so most environmental observations were qualitative and therefore subject to errors in judgment. These data present a more complete description of the stations than locality alone.

The field study was over a considerably larger area than is herein considered. Collections were made in brackish creeks in addition to fresh water. I am concerned here only with the species occurring in fresh water and have listed only the 120 freshwater stations, retaining the original field station numbers used in the overall survey. The general location of stations is shown in Figs. 1-2.

2. Colleton Co.; where U.S. 15 crosses a creek; 4.5 miles N of Walterboro; 5.5 miles S of Canadys. Ashepoo. May 30, 1956. Dark but clear. Muck.

3. Colleton Co.; creek in North Walterboro crossed by U. S. 15; 3.2 miles N of Walterboro; 1.25 miles S of station 2. Ashepoo. May 30, 1956. Dark but clear. Muck.

4. Colleton Co.; where S-15-88 crosses one fork of the Ashepoo R.; 1.4 miles E of U.S. 17A; 4.5 miles S of Walterboro. Ashepoo. May 30, 1956. Dark but clear. Muck.

8. Bamberg Co.; Clear Pond on unmarked dirt road just off secondary road S-5-59; 0.5 of a mile E of U.S. 601; 6.4 miles SSE of Bamberg. Combahee. June 16, 1956. Clear. Sand and muck.

9. Bamberg Co.; where U.S. 601 crosses Lemon Cr.; 1.25 miles S of Bamberg. Combahee. June 16, 1956. Dark but clear. Sand and muck.

10. Bamberg Co.; where U.S. 301 crosses Grapevine Cr., a tributary of Lemon Cr.; 1.3 miles SW of Bamberg. Combahee. June 16, 1956. Rocks and muck.



Fig. 2. The area studied in southeastern South Carolina. Station locations are indicated by large black dots.

11. Bamberg Co.; where U.S. 301 crosses the Little Salkehatchie R.; 5.4 miles SW of Bamberg. Combahee. June 16, 1956. Dark but clear. Sand and muck.

12. Bamberg Co.; where S-5-75 crosses Colston Branch, a tributary of the Little Salkehatchie R.; 9.4 miles S of Bamberg. Combahee. June 16, 1956. Dark but clear. Sand and muck.

13. Bamberg Co.; where S-5-21 crosses the Little Salkehatchie R.; 11.6 miles SSE of Bamberg; 4.3 miles ENE of Ehrhardt. Combahee. June 25, 1956. Dark but clear. Sand and muck.

14. Bamberg Co.; where S-5-87 crosses Savannah Cr.; 1.5 miles SW of Ehrhardt. Combahee. June 25, 1956. Dark but clear. Sand and muck.
15. Colleton Co.; where S.C. 641 crosses Savannah Branch; 5.2 miles W of Lodge. Combahee. June 25, 1956. Dark but clear. Sand and muck.
16. Allendale Co.-Bamberg Co.; where S.C. 641 crosses the Big Salkehatchie R.; 5.5 miles SW of Ehrhardt. Combahee. June 25, 1956. Dark but clear. Muck.
17. Bamberg Co.; where secondary road S-5-84 crosses Lemon Cr.; 8.8 miles SSE of Bamberg. Combahee. June 26, 1956. Stagnant. Sand and muck.
18. Bamberg Co.; where S-5-84 crosses the Little Salkehatchie R.; 8.9 miles S of Bamberg. Combahee. June 26, 1956. Dark but clear. Sand.
19. Bamberg Co.; where S-5-19 crosses Colston Branch; 5.4 miles E of Olar. Combahee. June 26, 1956. Dark but clear. Sand.
20. Bamberg Co.; on unmarked dirt road just off S.C. 64, where it crosses Birds Branch; 0.6 mile SE of Olar. Combahee. June 26, 1956. Dark but clear. Sand and muck.
21. Bamberg Co.; where U.S. 321 crosses the Little Salkehatchie R.; 1.7 miles NNE of Govan. Combahee. June 26, 1956. Dark but clear. Rocks, sand, and muck.
22. Bamberg Co.; where S.C. 70 crosses the headwaters of the Little Salkehatchie R.; 2.25 miles W of Denmark. Combahee. June 26, 1956. Dark but clear. Sand and muck.
23. Bamberg Co.-Barnwell Co.; where S.C. 64 crosses Georges Cr.; 1.75 miles WNW of Olar. Combahee. June 26, 1956. Dark but clear. Sand and muck.
24. Bamberg Co.-Colleton Co.; where S.C. 217 crosses the Little Salkehatchie R.; 5.25 miles ESE of Ehrhardt. Combahee. June 27, 1956. Sand and muck.
25. Colleton Co.; where S-15-27 crosses Willow Swamp, a tributary of the Little Salkehatchie R.; 4.7 miles SW of Williams. Combahee. June 27, 1956. Stagnant. Sand, muck, and organic debris.
26. Colleton Co.; where S.C. 63 crosses the Little Salkehatchie R. at the first of four bridges W of U.S. 21; 9.7 miles S of Williams. Combahee. June 27, 1956. Stagnant. Muck and organic debris.
27. Colleton Co.; overflow from a pond near Combahee R. just off a dirt road 0.25 of a mile SSE of U.S. 17A; 1.0 mile ENE of Yemassee. Combahee. July 23, 1956. Milky. Muck.
28. Beaufort Co.-Colleton Co.; where dirt road ends at the Combahee R., just off U.S. 17A; 0.7 mile SE of station 27. Combahee. July 23, 1956. Clear. Sand and muck.
29. Colleton Co.; where U.S. 21 crosses Black Cr.; 4.0 miles NW of U.S. 17; 4.5 miles N of Yemassee. Combahee. July 23, 1956. Clear. Sand and muck.

30. Colleton Co.; where S.C. 63 crosses the Little Salkehatchie R. at second bridge W of U.S. 21; 0.1 mile from station 26. Combahee. July 23-24, 1956. Clear. Muck and organic debris.

31. Colleton Co.; where U.S. 17A crosses the Ashepool R.; 0.5 mile WSW of Walterboro. Ashepool. July 24, 1956. Dark but clear. Muck and organic debris.

32. Colleton Co.; where U.S. 17 crosses Tupelo Swamp; 3.5 miles E of Ashepool. Ashepool. July 24, 1956. Dark but clear. Muck.

35. Hampton Co.; where S.C. 63 crosses a tributary of the Big Salkehatchie R. at second of three bridges; 5.5 miles ENE of Varnville. Combahee. July 26, 1956. Dark but clear. Sand and organic debris.

36. Hampton Co.; where U.S. 601 crosses the Coosawhatchie R.; 1.4 miles WSW of Hampton. Broad. July 26, 1956. Dark but clear. Sand and muck.

37. Allendale Co.-Hampton Co.; where U.S. 321 crosses the Coosawhatchie R.; 2.5 miles WSW of Brunson. Broad. August 13, 1956. Dark but clear. Sand, muck, and organic debris.

38. Hampton Co.; where S-25-49 crosses Blood Hill Cr., a tributary of Coosawhatchie R.; 3.5 miles SW of Brunson. Broad. August 13, 1956. Muddy. Muck.

39. Hampton Co.; where S.C. 363 crosses the Coosawhatchie R.; 2.25 miles WSW of Hampton. Broad. August 13, 1956. Muddy in spots, dark but clear in spots. Muck.

40. Hampton Co.; where S.C. 128 crosses the Coosawhatchie R.; 2.9 miles SSE of Varnville. Broad. August 13, 1956. Muddy in spots, dark but clear in spots. Muck.

42. Hampton Co.; an old mill pond and spillway below pond, crossed by S-25-17; 1.9 miles W of Yemassee. Broad. August 14, 1956. Dark but clear. Muck.

43. Hampton Co.-Jasper Co.; where S-25-36(S-27-87) crosses the Coosawhatchie R.; 3.7 miles SW of Early Branch. Broad. August 14, 1956. Dark but clear. Sand and muck.

44. Jasper Co.; where S.C. 128 crosses Cypress Cr., a tributary of the Coosawhatchie R.; 1.0 mile NNW of Grays. Broad. August 15, 1956. Dark but clear. Muck.

45. Jasper Co.; where S-27-108 crosses Cypress Cr., a tributary of Coosawhatchie R.; 2.3 miles NE of Grays. Broad. August 15, 1956. Dark but clear. Sand and muck.

51. Bamberg Co.; where U.S. 601 crosses the Little Salkehatchie R.; 9.3 miles S of Bamberg. Combahee. September 29, 1956. Clear. Sand and muck.

52. Colleton Co.; where S-15-41 crosses a tributary of the Ashepool R.; 5.75 miles SE of Walterboro. Ashepool. May 2, 1957. Clear. Muck. 64°.

54. Beaufort Co.-Colleton Co.; where dirt road ends at the Combahee R., just off U.S. 17A; 0.7 mile SE of station 27. Combahee. May 2, 1957. Clear. Sand and muck. 68°.

55. Barnwell Co.; where S-6-84 crosses Little Salkehatchie Cr.; 1.7 miles SE of Blackville. Combahee. June 10, 1957. Dark but clear. Sand and muck. 64°.

56. Barnwell Co.; spillway below dam at Barnwell State Park, just off S.C. 3; 0.5 mile S of Blackville. Combahee. June 10, 1957. Dark but clear. Rocks, sand, and muck. 74°.

57. Barnwell Co.; where S-6-67 crosses Turkey Cr.; 1.8 miles W of Blackville. Combahee. June 10, 1957. Dark but clear. Muck. 67°.

58. Barnwell Co.; where S-6-168 crosses Turkey Cr.; 1.1 miles N of Barnwell. Combahee. June 10, 1957. Dark but clear. Sand. 67°.

59. Barnwell Co.; where S.C. 28 crosses Buck Cr.; 4.0 miles NW of Barnwell. Combahee. June 10, 1957. Dark but clear. Sand. 67°.

60. Barnwell Co.; where S.C. 28 crosses the spillway of a pond on Rosemary Cr.; 5.75 miles NW of Barnwell. Combahee. June 10, 1957. Dark but clear. Sand. 71°.

61. Barnwell Co.; where S-6-185 crosses Rosemary Cr.; 1.25 miles S of Williston. Combahee. June 11, 1957. Dark but clear. Sand. 68°.

62. Barnwell Co.; where S-6-166 crosses the Big Salkehatchie R.; 3.2 miles NW of Barnwell. Combahee. June 11, 1957. Dark but clear. Sand. 68°.

63. Barnwell Co.; where S-6-20 crosses the Big Salkehatchie R.; 0.25 mile from western boundary of Barnwell. Combahee. June 11, 1957. Dark but clear. Sand and muck. 68°.

64. Barnwell Co.; where S.C. 28-37 crosses the Big Salkehatchie R.; 0.5 mile S of Barnwell. Combahee. June 11, 1957. Dark but clear. Sand and muck. 70°.

65. Barnwell Co.; where S.C. 64 crosses Hagood's Mill Cr.; 1.25 miles SE of Barnwell. Combahee. June 11, 1957. Dark but clear. Sand and muck. 68°.

66. Barnwell Co.; where S-6-14 crosses Hercules Cr.; 4.5 miles ESE of Barnwell. Combahee. June 11, 1957. Dark but clear. Sand. 70°.

67. Allendale Co.; where U.S. 301 crosses Log Branch; 0.9 mile NE of Allendale. Combahee. June 12, 1957. Dark but clear. Sand and muck. 70°.

68. Allendale Co.; where U.S. 321 crosses Jackson Cr., just below Tuten's Mill Pond; 0.75 mile SSE of Sycamore. Combahee. June 12, 1957. Dark but clear. Sand. 78°.

69. Allendale Co.; where S-3-19 crosses the Coosawhatchie R.; 4.0 miles SSE of Allendale. Broad. June 12, 1957. Dark but clear. Sand. 72°.

70. Allendale Co.; where S-3-47 crosses the Coosawhatchie R.; 1.6 miles S of Allendale. Broad. June 12, 1957. Dark but clear. Sand and muck. 72°.

71. Allendale Co.; where S-3-22 crosses the Coosawhatchie R.; 0.3 mile SSE of Allendale. Broad. June 12, 1957. Dark but clear. Sand and muck. 78°.

73. Jasper Co.; where S.C. 336 crosses a tributary of the New R.; 2.0 miles SW of Ridgeland. New. June 13, 1957. Dark but clear. Sand and clay. 77°.

74. Barnwell Co.; where S.C. 70 crosses Toby Cr.; 1.75 miles NE of Barnwell. Combahee. July 8, 1957. Clear. Sand. 70°.

75. Barnwell Co.; where an unmarked dirt road crosses Hercules Cr.; 3.7 miles E of Barnwell; 0.7 mile W of S-6-14. Combahee. July 8, 1957. Clear. Gravel and sand. 74°.

76. Barnwell Co.; where S.C. 300 crosses Hurricane Cr.; 2.4 miles SE of Barnwell. Combahee. July 8, 1957. Clear. Sand. 72°.

77. Barnwell Co.; where S-6-57 crosses the Salkehatchie R.; 6.25 miles S of Hilda. Combahee. July 8, 1957. Dark but clear. Sand. 77°.

78. Allendale Co.; where S-3-48 crosses a small tributary of the Salkehatchie R.; 3.75 miles ENE of Sycamore. Combahee. July 9, 1957. Clear. Sand. 73°.

79. Allendale Co.; where S-3-18 crosses Jackson Cr.; 2.8 miles NE of Fairfax. Combahee. July 9, 1957. Dark but clear. Sand, muck, and organic debris. 76°.

80. Allendale Co.; where S-3-69 crosses Duck Cr.; 1.8 miles SW of Fairfax. Broad. July 9, 1957. Dark but clear. Sand and muck. 84°.

81. Allendale Co.; where S.C. 641 crosses Miller Cr.; 0.3 mile E of Sycamore. Combahee. July 9, 1957. Dark but clear. Sand and muck. 75°.

82. Allendale Co.-Barnwell Co.; where S.C. 300 crosses Wells Branch; 1.4 miles NW of Ulmers. Combahee. July 10, 1957. Dark but clear. Sand and muck. 74°.

83. Allendale Co.; where S.C. 28 crosses Log Branch; 0.25 of a mile N of Allendale. Combahee. July 10, 1957. Dark but clear. Sand and muck. 80°.

84. Hampton Co.; where S-25-41 crosses Black Cr.; 3.9 miles SW of Hampton. Broad. July 10, 1957. Dark but clear. Gravel, sand, and muck. 79°.

85. Hampton Co.; where an unmarked dirt road W of U.S. 321 crosses Black Cr.; 1.4 miles SW of Luray. Broad. July 10, 1957. Dark but clear. Gravel, sand, muck, and organic debris. 79°.

86. Hampton Co.; where S.C. 631 crosses a tributary of Black Cr., between Estill and Lena; 0.4 mile E of Estill. Broad. July 11, 1957. Dark but clear. Muck. 79°.

87. Hampton Co.; where U.S. 601 crosses Briar Cr.; 4.1 miles NE of Estill. Broad. July 11, 1957. Dark but clear. Gravel and sand. 80°.

88. Hampton Co.; where an unmarked dirt road off S.C. 631 crosses Cypress Cr.; 2.9 miles NE of Furman. Broad. July 11, 1957. Dark but clear. Sand. 75°.

89. Hampton Co.; where an unmarked dirt road crosses Cypress Cr.; 4.5 miles ENE of Furman. Broad. July 11, 1957. Dark but clear. Sand. 77°.

90. Hampton Co.; where S-25-94 crosses John Pen Brook; 0.9 mile E of Furman. Broad. July 12, 1957. Dark but clear. Gravel, sand, muck, and organic debris. 78°.

91. Hampton Co.; where S-25-17 crosses Camp Brook; 3.3 miles ESE of Cummings. Broad. July 12, 1957. Dark but clear. Sand. 80°.

92. Hampton Co.; where S-25-17 crosses a tributary of the Coosawhatchie R.; 3.7 miles W of Early Branch. Broad. July 12, 1957. Muddy. Sand. 76°.

94. Colleton Co.; where S.C. 64 crosses Jones Swamp; 2.25 miles WNW of Walterboro. Ashepoo. July 23, 1957. Dark but clear. Sand, muck, and organic debris. 75°.

95. Colleton Co.; where S-15-49 crosses Jones Swamp; 3.75 miles NW of Walterboro. Ashepoo. July 23, 1957. Muddy in spots; dark but clear in spots. Sand and muck. 74°.

96. Colleton Co.; where S-15-89 crosses Jones Swamp; 2.75 miles NE of Stokes. Ashepoo. July 23, 1957. Dark but clear. Sand and organic debris. 77°.

97. Colleton Co.; where an unmarked dirt road just off S-15-50 crosses Jones Swamp; 4.8 miles NNE of Stokes. Ashepoo. July 23, 1957. Muddy. Sand. 89°.

98. Colleton Co.; where S-15-116 crosses Ireland Cr.; 4.6 miles NNE of Walterboro. Ashepoo. July 23, 1957. Dark but clear. Sand, muck, and organic debris. 75°.

99. Colleton Co.; where U.S. 17A crosses Fuller Swamp; 5.0 miles E of Walterboro. Ashepoo. July 23, 1957. Dark but clear. Sand and muck. 79°.

100. Colleton Co.; where S-15-45 crosses Chessey Cr.; 1.75 miles SSE of Round O. Ashepoo. July 23, 1957. Dark but clear. Sand and muck. 83°.

103. Colleton Co.; where S-15-41 crosses the Ashepoo R. (Ivanhoe Cr.); 3.7 miles NW of Green Pond; 0.8 mile SW of Ritter. Ashepoo. July 24, 1957. Dark but clear. Muck. 86°.

104. Colleton Co.; where S.C. 64 crosses Chessey Cr.; 4.4 miles ENE of Ritter. Ashepoo. July 24, 1957. Dark but clear. Muck. 81°.

105. Colleton Co.; where S.C. 64 crosses Horseshoe Cr.; 4.5 miles NNE of Ashepoo. Ashepoo. July 24, 1957. Dark but clear. Muck. 80°.

106. Colleton Co.; where S-15-41 crosses a tributary of Calpen Swamp; 3.8 miles NNW of White Hall. Combahee. July 24, 1957. Dark but clear. Sand and muck.

107. Colleton Co.; where S-15-28 crosses Black Cr.; 4.25 miles WNW of Hendersonville. Combahee. July 24, 1957. Dark but clear. Muck.

108. Colleton Co.; where U.S. 21 crosses Sandy Run Cr.; 7.75 miles WNW of Hendersonville. Combahee. July 25, 1957. Dark but clear. Sand.

109. Colleton Co.; where S.C. 64 crosses the Little Salkehatchie R. at the third of three bridges WNW of Bells Crossroads; 3.6 miles W of Ruffin. Combahee. July 25, 1957. Dark but clear. Sand.

112. Colleton Co.; where U.S. 21 crosses Indian Cr.; 4.7 miles E of Islandton. Combahee. July 29, 1957. Dark but clear. Sand and muck. 74°.

113. Colleton Co.; where S-15-33 crosses Indian Cr.; 5.25 miles SSE of Ruffin. Combahee. July 29, 1957. Dark but clear. Sand. 80°.

114. Colleton Co.; where S.C. 63 crosses Deep Cr.; 2.5 miles ESE of Islandton. Combahee. July 29, 1957. Dark but clear. Muck. 75°.

115. Colleton Co.; where S.C. 63 crosses Ricepatch Cr. at Islandton. Combahee. July 29, 1957. Dark but clear. Sand, muck, and organic debris. 75°.

116. Colleton Co.; where U.S. 21 crosses Buckhead Cr.; 1.25 miles N of Ruffin. Combahee. July 31, 1957. Dark but clear. Sand and muck. 74°.

117. Colleton Co.; where S-15-74 crosses Buckhead Cr.; 3.6 miles NNE of Ruffin. Combahee. July 31, 1957. Dark but clear. Sand. 76°.

118. Colleton Co.; where S-15-63 crosses Buckhead Cr.; 2.3 miles NW of Smoaks. Combahee. July 31, 1957. Dark but clear. Sand, muck, and organic debris. 76°.

119. Bamberg Co.-Colleton Co.; where S.C. 217 crosses a tributary of the Little Salkehatchie R.; 0.5 mile W of Padgetts. Combahee. July 31, 1957. Dark but clear. Sand and muck. 76°.

120. Colleton Co.; where S.C. 641 crosses Willow Swamp; 1.75 miles S of Lodge. Combahee. July 31, 1957. Dark but clear. Muck and clay. 76°.

121. Colleton Co.; where S-15-18 crosses Fender Cr.; just W of the center of Lodge. Combahee. July 31, 1957. Dark but clear. Sand and muck. 76°.

122. Colleton Co.; where S-15-18 crosses a tributary of Willow Swamp; 1.5 miles SW of Lodge. Combahee. July 31, 1957. Dark but clear. Sand, muck, and organic debris. 77°.

123. Colleton Co.; where S-15-65 crosses Fuller Swamp; 5.1 miles ENE of Walterboro. Ashepoo. July 31, 1957. Dark but clear. Sand and muck. 78°.

124. Colleton Co.; where U.S. 17A crosses Chessey Cr.; 1.5 miles WNW of Cottageville. Ashepoo. July 31, 1957. Dark but clear. Sand and muck. 77°.

125. Hampton Co.; where S-25-44 crosses Deep Branch; 3.7 miles NNE of Early Branch. Combahee. August 1, 1957. Dark but clear. Sand, muck, and organic debris. 77°.

126. Hampton Co.; where S-25-13 crosses Whippy Swamp; 2.9 miles SSE of Miley. Combahee. August 1, 1957. Dark but clear. Sand and muck. 76°.

127. Hampton Co.; where U.S. 601 crosses Whippy Swamp; 1.25 miles WSW of Miley. Combahee. August 1, 1957. Dark but clear. Sand and muck. 80°.

128. Hampton Co.; where S-25-43 crosses Whippy Swamp; 4.3 miles WNW of Miley. Combahee. August 1, 1957. Dark but clear. Sand, muck, and organic debris. 75°.

129. Jasper Co.; where S.C. 631 crosses Cypress Cr.; 2.0 miles WNW of Grays. Broad. August 12, 1957. Dark but clear. Sand and muck. 76°.

130. Jasper Co.; where S.C. 128 crosses a tributary of the Coosawhatchie R.; 0.8 mile N of Gillisonville. Broad. August 12, 1957. Dark but clear. Sand and muck. 76°.

132. Jasper Co.; where S-27-115 crosses a tributary of the headwaters of the New R.; 4.4 miles NW of Ridgeland. New. August 13, 1957. Dark but clear. Sand. 76°.

133. Jasper Co.; where S-27-115 crosses a tributary of the headwaters of the New R.; 3.7 miles WNW of Ridgeland. New. August 13, 1957. Dark but clear. Muck. 82°.

134. Jasper Co.; where S-27-39 crosses the New R.; 1.8 miles WNW of Ridgeland. New. August 13, 1957. Dark but clear. Sand and muck. 78°.

135. Jasper Co.; where S-27-29 crosses the New R.; 1.5 miles WSW of Ridgeland. New. August 13, 1957. Dark but clear. Sand and muck. 80°.

136. Jasper Co.; where U.S. 17 crosses the New R.; 1.6 miles SW of Switzerland. New. August 13, 1957. Dark but clear. Sand and muck. 78°.

138. Jasper Co.; where S.C. 128 crosses Beaver Dam Cr.; 1.3 miles SE of Grays. Broad. August 14, 1957. Dark but clear. Muck. 78°.

139. Jasper Co.; where an unmarked dirt road just off U.S. 17 crosses Bees Cr.; 2.25 miles NNE of Ridgeland. Broad. August 14, 1957. Dark but clear. Muck. 84°.

140. Jasper Co.; where U.S. 17 passes alongside a drainage ditch, a tributary of the New R.; 2.2-2.3 miles SW of Switzerland. New. August 14, 1957. Dark but clear. Muck. 95°.

160. Colleton Co.; where S-15-41 crosses the Ashepoo R. (Ivanhoe Cr.); 3.7 miles NW of Green Pond; 0.8 mile SW of Ritter. Ashepoo. May 25, 1959. Dark but clear. Muck. (Same locality as station 103).

SPECIES OF FISH

No previous extensive work on the fishes of this area has been done. In several collections, Freeman (1954) obtained 14 species from a pond and a stream, north branch of the Salkehatchie River, Barnwell County, in the Atomic Energy Commission's Savannah River Plant Area.

I collected and identified approximately 13,850 specimens representing 9 orders, 17 families, 31 genera, and 53 species. A

number of specimens were too small or too immature to be readily relegated to any species. Included in this group were members of the following genera: *Erimyzon*, *Lepomis*, *Emneacanthus*, *Elassoma*, and *Etheostoma* (*Hololepis*). The bulk of the collections is in the Charleston Museum, Charleston, South Carolina; but some specimens have been placed in the U.S. National Museum, Washington, D.C.

The list of species contains: order; family; scientific name and usually at least one common name; list of records of the species from the study area, if it has been previously reported (occasionally, after the list of previous records, references are included to works giving especially useful information on the particular species); number of specimens collected; and list of the stations from which the species was obtained.

ORDER SEMIONOTIFORMES

Family Lepisosteidae

Lepisosteus osseus (Linnaeus). Longnose gar

37 specimens, from stations 26, 37, 84, 86, 91, 99, 104, 105, 109, 112, 116-118, 120-121, 126, 128, 134.

ORDER AMIIFORMES

Family Amiidae

Amia calva Linnaeus. Bowfin; Mudfish

6 specimens, from stations 21, 88, 100, 129, 136, 138.

ORDER CLUPEIFORMES

Family Umbridae

Umbra pygmaea (DeKay). Eastern mudminnow

25 specimens, from stations 52 and 100.

Family Esocidae

Esox americanus Gmelin. Redfin pickerel

Esox americanus Gmelin. Freeman, 1954, p. 133, '148, Salkehatchie River.

698 specimens, from stations 2-4, 9-15, 17-26, 30, 32, 35-40, 43-45, 52, 56-57, 59, 64, 69, 73-74, 76, 78-91, 94-98, 100, 103-104, 108-109, 112-127, 130, 133-135, 138-139, 160.

Esox niger LeSueur. Chain pickerel

Esox niger LeSueur. Freeman, 1954, p. 134, 148, Salkehatchie River.

142 specimens, from stations 11, 13, 17-18, 21, 24, 29, 35, 39-40, 43-45, 54, 77, 91, 94-95, 98, 103, 105, 107-109, 112, 114, 116-118, 120-122, 125, 129-130, 160.

ORDER CYPRINIFORMES

Family Cyprinidae

Notemigonus crysoleucas (Mitchill). Golden shiner

Notemigonus crysoleucas bosci (Valenciennes). Fowler, 1945, p. 168-170, Ashepoo River.

Notemigonus bosci (Valenciennes). Fowler, 1935, p. 10-11, New River (probably).

1,068 specimens, from stations 2, 9-12, 14-15, 19, 25-26, 30, 32, 38-40, 43-45, 60, 71, 73, 80, 83-92, 95, 97-100, 103-106, 112, 114-117, 119, 122-127, 129-130, 132-136, 138-140.

Opsopoeodus emiliae Hay. Pugnose minnow

Opsopoeodus emiliae Hay. Anderson, MS, Combahee River (specimens listed below).

26 specimens, from stations 14, 17, 18, 24, 35, 67, 79, 81.

Notropis stonei Fowler. Sailfin shiner

Notropis stonei Fowler. Suttkus, 1951, p. 83-84, Combahee and Broad Rivers.

R. D. Suttkus now considers *N. stonei* as a subspecies of *N. hypselopterus* (personal communication).

Erogala formosa (Putnam). Fowler, 1935, p. 16, Combahee River.

980 specimens, from stations 9, 11-24, 29, 35, 37, 55, 57-59, 61-63, 65-67, 69-70, 74-79, 81-82, 84, 89, 109, 126, 128.

Notropis cummingsae Myers. Dusky shiner

Notropis c. cummingsae Myers. Hubbs and Raney, 1951, p. 6-7, Combahee River.

1,125 specimens, from stations 9, 11-19, 21-24, 30, 35, 43, 54, 58-63, 65-67, 75-77, 79, 81-82, 109, 126, 128.

Notropis chalybaeus (Cope). Ironcolor shiner

Notropis chalybaeus (Cope). Fowler, 1945, p. 30, Little Salkehatchie River.

Hydrophlox chalybaeus (Cope). Fowler, 1935, p. 14, Combahee River.
Cope, 1869, p. 383.

1,149 specimens, from stations 9, 10-19, 21-25, 30, 35-37, 39, 43-45, 51, 57, 60, 64, 71, 75, 77, 79, 81, 84-85, 88, 109, 112, 119, 126-127.

Notropis petersoni Fowler. Coastal shiner

219 specimens, from stations 9-19, 21-25, 30, 35, 37, 54, 57, 60, 62-63, 67, 79, 81-82, 126, 128.

Notropis maculatus (Hay). Taillight shiner

59 specimens, from stations 12, 25, 30, 32, 35, 40, 45, 51, 84, 109, 112, 117, 121, 126-128.

Family Catostomidae

Minytrema melanops (Rafinesque). Spotted sucker

Minytrema melanops (Rafinesque). Fowler, 1935, p. 10, Combahee River.
11 specimens, from stations 15, 30, 57, 74, 84.

Erimyzon sp.

154 specimens, from stations 25, 30, 40, 70-71, 73, 77, 80, 89, 94-96, 103, 105, 108-109, 112, 115-116, 125-126, 129, 134.

Erimyzon sucetta (Lacépède). Lake chubsucker

Erimyzon sucetta (Lacépède). Fowler, 1935, p. 9, New (probably) and Combahee Rivers.

Erimyzon s. sucetta (Lacépède). Fowler, 1945, p. 168, Great Swamp Creek, 49 miles south of Charleston on U.S. 17 (Ashepoo, probably). Freeman, 1954, p. 134, 148, Salkehatchie River.

100 specimens, from stations 26, 61, 83, 85, 87-88, 100, 117, 120, 122, 130, 132-133, 135-136, 140.

Erimyzon oblongus (Mitchill). Creek chubsucker

263 specimens, from stations 2, 9-11, 19, 23, 38, 55, 84-86, 98, 119, 121-123, 127.

Family Ictaluridae

Ictalurus catus (Linnaeus). White catfish

1 specimen, from station 105.

Ictalurus platycephalus (Girard). Flat bullhead

1 specimen, from station 30.

Ictalurus natalis (LeSueur). Yellow bullhead

Ameiurus natalis (LeSueur). Fowler, 1935, p. 18, Combahee River.

81 specimens, from stations 4, 27, 29, 38, 40, 43-44, 68, 80, 84, 86-88, 95, 99, 103-104, 108, 112, 116-117, 124-125, 129-130, 139.

Ictalurus nebulosus (LeSueur). Brown bullhead

12 specimens, from stations 59 and 60.

Noturus gyrinus (Mitchill). Tadpole madtom

Schilbeodes mollis (Hermann). Freeman, 1954, p. 138, 148, Salkehatchie River. (*S. mollis* is considered a synonym of *N. gyrinus*, personal communication with Reeve M. Bailey.)

Hubbs and Raney, 1944, p. 25-26.

46 specimens, from stations 4, 21, 30, 38, 44, 57, 64, 66, 68, 105, 116.

Noturus leptacanthus Jordan. Speckled madtom

7 specimens, from stations 23, 58-59, 81.

ORDER ANGUILLIFORMES

Family Anguillidae

Anguilla rostrata (LeSueur). American eel

Muraena bostonensis LeSueur. Fowler, 1945, p. 167, Combahee River.

56 specimens, from stations 4, 13-14, 24, 51, 69-70, 81, 88, 99, 123-124, 126.

ORDER CYPRINODONTIFORMES

Family Cyprinodontidae

Fundulus chrysotus (Günther). Golden topminnow

Zygonectes chrysotus (Günther). Fowler, 1935, p. 20-21, New River (Probably).

Brown, 1957, p. 70-73, p. 75.

Miller, 1955, p. 10.

28 specimens, from stations 103 and 160.

Fundulus notti (Agassiz). Starhead topminnow

Fundulus notti lineolatus (Agassiz). Brown, 1958, p. 480, (Colleton County; Ireland Creek, tributary Ashpoo River), (Bamberg County; Little Salkehatchie River between Denmark and Hilda, Route 70), (Jasper County; Great Swamp, tributary New River).

Fundulus dispar lineolatus (Agassiz). Freeman, 1954, p. 139, 148, Salkehatchie River.

Brown, 1957, p. 70-73, p. 76.

Miller, 1955, p. 10.

82 specimens, from stations 9, 25, 27, 39-40, 42, 44-45, 75, 83, 86, 91, 94-95, 97-98, 103, 107-108, 112-113, 116-117, 125, 127, 129, 133-135, 140.

Family Poeciliidae

Gambusia affinis (Baird and Girard). Mosquitofish

Gambusia holbrooki (Agassiz). Fowler, 1945, p. 173, Combahee River and Great Swamp Creek, 49 miles south of Charleston on U.S. 17 (probably Ashepoo drainage).

Gambusia affinis holbrooki (Girard). Freeman, 1954, p. 139, 148, Salkehatchie River.

3,517 specimens, from stations 3, 4, 8-10, 12-15, 17, 19, 21, 23-25, 27-32, 35-40, 42-45, 51-52, 60, 64, 67-69, 71, 77, 80-81, 84-88, 90-91, 94-100, 103-106, 108-109, 112, 114, 116-117, 119-120, 122-124, 126-127, 129-130, 132-136, 138-140, 160.

Mollienesia latipinna LeSueur. Sailfin molly

3 specimens, from station 32.

Heterandria formosa Agassiz. Least killifish

27 specimens, from stations 32, 52, 103, 106, 136, 160.

Family Amblyopsidae

Chologaster cornuta Agassiz. Swampfish

6 specimens, from stations 2, 30, 73, 160.

ORDER PERCOPSIFORMES

Family Aphredoderidae

Aphredoderus sayanus (Gilliams). Pirate perch

Aphredoderus sayanus (Gilliams). Freeman, 1954, p. 139, 148, Salkehatchie River.

404 specimens, from stations 2, 9, 13-15, 17, 19, 21-25, 29-30, 32, 35-36, 38-40, 43-45, 51-52, 57, 59, 61, 64, 69-71, 77-87, 89, 94-96, 100, 103-105, 108-109, 112-114, 116-117, 119-122, 124-127, 129-130, 132, 134-136, 139, 160.

ORDER PERCIFORMES

Family Centrarchidae

Micropterus salmoides (Lacépède). Largemouth bass

Micropterus s. salmoides (Lacépède). Freeman, 1954, p. 140, 148, Salkehatchie River.

Bailey and Hubbs, 1949, p. 18-20.

Hubbs and Bailey, 1940, p. 37-39.

122 specimens, from stations 8-9, 19, 27-28, 30, 38, 40, 42, 45, 56, 60, 68, 71, 74, 77, 79-80, 84, 91, 103-104, 109, 112, 116-117, 119-120, 125-126, 128-129, 132-136, 160.

Chaenobryttus gulosus (Cuvier). Warmouth

Chaenobryttus gulosus (Cuvier). Fowler, 1935, p. 25, Combahee River.

Chaenobryttus coronarius Bartram. Freeman, 1954, p. 140, 148, Salkehatchie River.

124 specimens, from stations 2, 9, 11, 13, 19, 21, 24-25, 30, 32, 38-40, 43-45, 51-52, 56, 59-60, 69, 75, 79, 86, 95, 100, 104-105, 112, 116, 121, 124-125, 133-136, 138, 160.

Lepomis sp.

14 specimens, from stations 29, 39, 68, 84, 88, 109, 132, 134.

Lepomis punctatus (Valenciennes). Spotted sunfish

34 specimens, from stations 12-15, 17, 22, 24, 32, 35-36, 51, 58, 69, 80-81, 96, 99, 109.

Lepomis gibbosus (Linnaeus). Pumpkinseed

11 specimens, from stations 15, 25, 26, 32, 122.

Lepomis microlophus (Günther). Redear sunfish; Shellcracker

1 specimen, from station 56.

Lepomis auritus (Linnaeus). Redbreast

173 specimens, from stations 2, 9, 14, 18-19, 22, 25, 27-28, 37-38, 42-43, 55, 57, 79, 82-85, 89, 95, 97-98, 105, 109, 117, 119-120, 123, 126, 128, 130, 133-134, 136, 140.

Lepomis marginatus (Holbrook). Dollar sunfish; Redeye

[?] *Lepomis megalotis* (Rafinesque). Fowler, 1935, p. 24, New (probably) and Combahee rivers.

Lepomis marginatus (Holbrook). Freeman, 1954, p. 141, 148, Salkehatchie River.

165 specimens, from stations 2-3, 10-12, 22-23, 25, 30, 36-40, 43, 55, 59-61, 75, 80-82, 84, 86, 89, 96-98, 100, 112, 115, 117-118, 120-123, 126-127, 133-135, 140.

Lepomis macrochirus Rafinesque. Bluegill; Bream

Lepomis macrochirus purpureus Cope. Freeman, 1954, p. 142, 148, Salkehatchie River.

508 specimens, from stations 8-13, 15, 17, 19, 21-22, 24-27, 30, 39-40, 42-43, 51, 54-56, 59-60, 67-69, 71, 74, 80, 82-83, 85, 91, 98, 109, 121-122, 125-127, 129-130, 133, 136, 140.

Enneacanthus sp.

17 specimens, from stations 83, 86, 95, 104.

Enneacanthus obesus (Girard). Banded sunfish

168 specimens, from stations 2, 22, 25-26, 31-32, 36-37, 39, 43-44, 69, 87, 96, 98-100, 103, 105-106, 114-117, 123-124, 133, 138-139.

Enneacanthus gloriosus (Holbrook). Bluespotted sunfish

41 specimens, from stations 21, 29, 37, 45, 69, 91, 94, 108, 127, 134-136, 160.

Enneacanthus chaetodon (Baird). Blackbanded sunfish

2 specimens, from station 29.

Pomoxis nigromaculatus (LeSueur). Black crappie

10 specimens, from stations 40, 80, 105, 140.

Acantharchus pomotis (Baird). Mud sunfish

45 specimens, from stations 21, 26, 30, 38-40, 43, 52, 86-87, 90-91, 94, 99, 104, 106, 124, 133, 160.

Centrarchus macropterus (Lacépède). Flier

Centrarchus macropterus (Lacépède). Freeman, 1954, p. 142, 148, Salkehatchie River.

1,724 specimens, from stations 2, 9-12, 14-15, 19, 26, 29, 32, 36-40, 42-44, 52, 59-60, 69, 71, 73, 79-80, 82-92, 94-95, 97, 99-100, 103-106, 108, 112-117, 119, 123-125, 127, 129-130, 132-136, 138-139.

Elassoma sp.

1 specimen, from station 13.

Elassoma zonatum Jordan. Banded pygmy sunfish

Elassoma zonatum Jordan. Freeman, 1954, p. 143, 148, Salkehatchie River.

15 specimens, from stations 12, 29-30, 44, 69, 85, 87, 103-104, 106, 109, 117.

Elassoma evergladei Jordan. Everglades pygmy sunfish

Böhlke, 1956, p. 4.

3 specimens, from stations 21, 87, 139.

Family Percidae

Percina nigrofasciata (Agassiz). Blackbanded darter

[?] *Alvordius peltatus* (Cope). Fowler, 1935, p. 22, Combahee River.

[?] *Hadropterus peltatus crassus* (Jordan and Brayton). Fowler, 1945, p. 195, Combahee River.

Percina n. nigrofasciata x *Percina n. raneyi* (Intergrades). Crawford, 1956, p. 50, Combahee River system.

7 specimens, from stations 15, 24, 58, 75, 79, 82.

Etheostoma olmstedi Storer.

Etheostoma olmstedi. Cole, 1958, p. 1156, Santee-Cooper system southward to the St. Johns River.

71 specimens, from stations 9, 12, 14-15, 17-18, 21-24, 59, 62, 66-67, 79, 81-82.

Etheostoma fricksium Hildebrand. Savannah darter

Etheostoma fricksium Hildebrand. Anderson, MS, Combahee River (the specimens listed below).

Hildebrand, 1923, p. 7-8.

11 specimens, from stations 15, 23-24, 59, 76, 81-82.

Etheostoma (Hololepis) sp.

1 specimen, from station 82.

Etheostoma serriferum (Hubbs and Cannon). Sawcheek darter

Hololepis serrifer Hubbs and Cannon. Hubbs and Cannon, 1935, p. 31-36, Combahee River. Fowler, 1945, p. 196, Combahee River.

Collette, 1962, p. 125-133.

7 specimens, from stations 30, 36, 105, 109, 116.

Etheostoma fusiforme barratti (Holbrook). Scalyhead darter

Boleichthys fusiformis (Girard). Fowler, 1935, p. 23, Combahee River.

Hololepis barratti (Holbrook). Hubbs and Cannon, 1935, p. 54-62, Combahee River. Fowler, 1945, p. 195, Combahee River.

Etheostoma barratti (Holbrook). Freeman, 1954, p. 144, 148, Salkehatchie River.

Collette, 1962, p. 150-190.

5 specimens, from stations 52, 69, 95.

Family Ehippidae

Chaetodipterus faber (Broussonet). Atlantic spadefish

Chaetodipterus faber (Broussonet). Anderson, MS, Ashepoo River (the specimens listed below).

Hildebrand and Cable, 1938, p. 534-543.

1 specimen, from station 103.

Family Atherinidae

Labidesthes sicculus (Cope). Brook silverside

237 specimens, from stations 9, 11-13, 17, 21-22, 28, 30, 42-43, 45, 54, 67-68, 80, 91, 94, 105, 112, 126, 128-129, 133-134.

ORDER PLEURONECTIFORMES

Family Soleidae

Trinectes maculatus (Bloch and Schneider). Hogchoker

Hubbs, 1932, p. 19-21.

1 specimen, from station 105.

STATION OF SPECIAL INTEREST

It is impossible to discuss all collecting localities at length, but one is worthy of comment. Station 32 (Tupelo Swamp, Ashpoo drainage, Colleton County, July 24, 1956) is a typical, small, black-water creek. On the date of collection the stream was not flowing and was $\frac{1}{2}$ to $3\frac{1}{2}$ feet deep and 10 to 75 feet wide. Literally hundreds of fish were heard and observed breaking the surface of the water beneath the highway bridge and in its vicinity, and many *Gambusia* were seen swimming at the surface. About six or eight seine hauls were made, mostly beneath the bridge. Collecting at this station did not yield a great number of species, but many specimens were taken, particularly *Gambusia* and *Centrarchus*. *Centrarchus macropterus* was the species largely heard and observed breaking the surface of the water. The following list gives the species and numbers of specimens collected: *Esox americanus*, 3; *Notemigonus crysoleucas*, 43; *Notropis maculatus*, 2; *Gambusia affinis*, 2,020 $\pm$; *Mollienesia latipinna*, 3; *Heterandria formosa*, 5; *Aphredoderus sayanus*, 1; *Chaenobryttus gulosus*, 34; *Lepomis punctatus*, 1; *Lepomis gibbosus*, 4; *Enneacanthus obesus*, 4; and *Centrarchus macropterus*, 542.

DISCUSSION

Twenty-five species were collected that have not been reported from the area. Many other species were found that have not been recorded from one or more of the drainages. Table 1 gives a compilation of new records.

All freshwater fish reported in the literature for this area were collected in at least one of the drainages studied. *Fundulus chrysotus* and *Etheostoma fusiforme barratti* have been recorded from drainages in the area other than those in which I found them (*Fundulus chrysotus* from New and *Etheostoma fusiforme barratti* from Combahee).

TABLE 1
New records of fish

Species	Entire Area	Ashe-poo	Comba-hee	Broad	New
<i>Lepisosteus osseus</i>	X	X	X	X	X
<i>Amia calva</i>	X	X	X	X	X
<i>Umbra pygmaea</i>	X	X			
<i>Esox americanus</i>		X		X	X
<i>Esox niger</i>		X		X	
<i>Notemigonus crysoleucas</i>			X	X	
<i>Notropis cummingsae</i>				X	
<i>Notropis chalybaeus</i>				X	
<i>Notropis petersoni</i>	X		X	X	
<i>Notropis maculatus</i>	X	X	X	X	
<i>Minytrema melanops</i>				X	
<i>Erimyzon sucetta</i>				X	
<i>Erimyzon oblongus</i>	X	X	X	X	
<i>Ictalurus catus</i>	X	X	X		
<i>Ictalurus platycephalus</i>	X		X		
<i>Ictalurus natalis</i>		X		X	
<i>Ictalurus nebulosus</i>	X		X		
<i>Noturus gyrinus</i>		X		X	
<i>Noturus leptacanthus</i>	X		X		
<i>Anguilla rostrata</i>		X		X	
<i>Fundulus chrysotus</i>		X			
<i>Fundulus notti</i>				X	
<i>Gambusia affinis</i>				X	X
<i>Mollienesia latipinna</i>	X	X			
<i>Heterandria formosa</i>	X	X	X		X
<i>Chologaster cornuta</i>	X	X	X		X
<i>Aphredoderus sayanus</i>		X		X	X
<i>Micropterus salmoides</i>		X		X	X
<i>Chaenobryttus gulosus</i>		X		X	X
<i>Lepomis punctatus</i>	X	X	X	X	
<i>Lepomis gibbosus</i>	X	X	X		
<i>Lepomis microlophus</i>	X		X		
<i>Lepomis auritus</i>	X	X	X	X	X
<i>Lepomis marginatus</i>		X		X	
<i>Lepomis macrochirus</i>		X		X	X
<i>Enneacanthus obesus</i>	X	X	X	X	X
<i>Enneacanthus gloriosus</i>	X	X	X	X	X
<i>Enneacanthus chaetodon</i>	X		X		
<i>Pomoxis nigromaculatus</i>	X	X		X	X
<i>Acantharchus pomotis</i>	X	X	X	X	X
<i>Centrarchus macropterus</i>		X		X	
<i>Elassoma zonatum</i>		X		X	
<i>Elassoma evergladei</i>	X		X	X	
<i>Etheostoma serriferum</i>		X		X	
<i>Etheostoma fusiforme barratti</i>		X		X	
<i>Labidesthes sicculus</i>	X	X	X	X	X
<i>Trinectes maculatus</i>	X	X			

With the exception of *Notemigonus crysoleucas* in the Ashepoo and New drainages and *Notropis maculatus* in the Ashepoo, there was a scarcity of cyprinids in these two river drainages. Two factors may have contributed to this. Experience has shown that the greater the number of areas sampled from a given drainage the greater the number of species one can expect to capture until all species occurring in the drainage have been collected. There were only 19 stations in the Ashepoo drainage and 7 in the New drainage, as compared with 68 in the Combahee drainage and 26 in the Broad drainage. From the smaller number of stations seined in the Ashepoo and New drainages it might be expected that the total number of species collected from these systems would be smaller than the total number from the Combahee and Broad drainages. There was, however, not nearly so marked a difference in the number of centrarchid species obtained from the various drainages. Probably a more valid reason for the dearth of cyprinids in the Ashepoo and New is that these drainages apparently lack stream environments which are especially conducive to habitation by cyprinids. The headwaters of the Combahee and Broad drainages flow through areas with considerably more elevation differential than do the headwaters of the Ashepoo and New drainages and, as a consequence, the Combahee and Broad drainages (especially the Combahee) have many relatively fast, small creeks, which may be called "minnow" streams.

One specimen of *Trinectes maculatus* was taken in fresh water in the Ashepoo drainage. Hildebrand and Cable (1938, p. 630) and Gunter (1957, p. 14) mention several records of *T. maculatus* occurring in fresh water.

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*U. S. Bureau of Commercial Fisheries Biological Laboratory,
Brunswick, Georgia. Contribution Number 70.*

NEW RECORDS OF FISHES FOR SOUTH CAROLINA, AND THE OCCURRENCE OF *CHAETODIPTERUS FABER* IN FRESH WATER.—Collections of fishes from several coastal plain streams and estuaries in southeastern South Carolina in March, June, July, and August 1956, and May, June, July, and August 1957, produced new records for South Carolina for two species, range extensions for three species, and a small specimen of a marine species from a freshwater environment.

South Carolina has been included in the range of *Menidia beryllina* (Cope) and *Oligoplites saurus* (Bloch and Schneider), but I found no specific reference in the literature to their occurrence in this state. I collected 218 specimens of *M. beryllina* from the Combahee (Colleton County), Coosaw (Beaufort County), Broad (Beaufort and Jasper counties), and May (Beaufort County) river drainages; and 24 specimens of *O. saurus* from the Beaufort, Broad, Coosaw, and May river drainages (Beaufort County).

The range of *Opsopoeodus emiliae* Hay is stated by Moore (1957, *In* Blair *et al.*, *Vertebrates of the United States*. McGraw-Hill Book Co. 31-210:107) as: "lowland streams of Great Lakes region; throughout the Mississippi Valley and Gulf Coast from Texas to Florida and Georgia." I collected 26 specimens in the Combahee River drainage (Allendale, Bamberg, Colleton, and Hampton counties). Carter Gilbert, Department of Biology, University of Florida, reported (personal communication) having examined specimens of *O. emiliae* from as far north as the Edisto River drainage in Orangeburg County, South Carolina.

Etheostoma fricksium Hildebrand has been recorded from the Savannah River basin only. This study produced 11 specimens from the Combahee drainage (Allendale, Bamberg, Barnwell, and Colleton counties).

Briggs (1958, *Bull. Fla. St. Mus., Biol. Sci.* 2(8):280) stated that *Diapterus olisthoto-*

mus (Goode and Bean) ranges from north-eastern Florida to Bahia, Brazil. I collected 9 specimens from the Coosaw, the Colleton-Chechessee, and the Beaufort river drainages (Beaufort County). In addition, I examined 2 specimens of *D. olisthostomus* captured by beach seine from off Cumberland Island, Georgia, in the summer of 1956, which now are in the collections of the U. S. Bureau of Commercial Fisheries, Biological Laboratory, Brunswick, Georgia.

Five specimens of *Chaetodipterus faber* (Broussonet) were collected from Coosaw and Broad drainages (Beaufort County) and Ashepoo drainage (Colleton County). All were caught in brackish water except for a small specimen, 16.5 mm total length, obtained on 24 July 1957, from a freshwater stream, the Ashepoo River in Colleton County. This locality is 7-8 miles above tidal influence, approximately 39 miles, by river, from St. Helena Sound. The small size of this specimen indicates that it was

young of the year. I found no record of the occurrence of either young or adults of this species in fresh water. According to Hildebrand and Cable (1938, *Bull. U. S. Bur. Fish.* 48(24):534-543), *C. faber* may spawn offshore, at least in the vicinity of Beaufort, North Carolina. The occurrence of a young spadefish in fresh water has not been explained. Hildebrand and Cable (*op. cit.* 536) suggested that spawning of *C. faber* at Beaufort, North Carolina, takes place at least during June. They also saw females with developing roe at Beaufort, North Carolina, on 25 May 1916. I was unsuccessful in a subsequent attempt, on 25 May 1959, to obtain additional specimens of spadefish from the locality of the capture of the small specimen.—WILLIAM D. ANDERSON, JR., U. S. Bureau of Commercial Fisheries, Biological Laboratory, Brunswick, Georgia. Contribution No. 67 from U. S. Bureau of Commercial Fisheries, Biological Laboratory, Brunswick, Georgia.

Sapelo Island, Georgia, in the midst of one of the richest and most extensive estuarine areas of the United States, was the site for the Conference on Estuaries sponsored by the Sapelo Island Research Station, Inc.; University of Georgia Marine Institute; U.S. Bureau of Commercial Fisheries Biological Laboratory, Brunswick, Georgia; Atlantic Estuarine Research Society; and the American Society of Limnology and Oceanography. Contributors were the National Science Foundation, Atomic Energy Commission, Office of Naval Research, and the Marine Fishing Institute. More than 500 registrants and about 50 non-registrants attended.

The over-all objectives of the Conference were: 1) To provide an opportunity for interdisciplinary exchange of ideas between individuals and groups active in estuarine research; 2) To critically summarize the status of knowledge relating to the natural characteristics of estuaries; 3) To delineate the direction of current research efforts in the estuarine environment.

The program was organized in a series of plenary sessions interspersed with series

of three concurrent symposia during the period of March 31 through April 3. There were some 90 participants, including representation from Germany, Netherlands, England, France, Australia, Denmark, Nigeria, Canada, Spain, Union of South Africa, Norway, Portugal, Italy, and New Zealand.

On Tuesday morning a plenary session was devoted to the problem of "what is an estuary?" Several interesting viewpoints were presented indicating that perhaps each man's description is geared to include those provinces he holds dear. The Tuesday afternoon plenary session was devoted to the origin of estuaries, circulation and diffusion, and sediment transport and sedimentation. On Tuesday evening there was a plenary symposium on instrumentation in estuarine research.

Wednesday morning three concurrent symposia were convened in the diverse fields of geomorphology and coastal processes, estuarine fisheries, and nutrients and carbon sources in estuaries. The Wednesday afternoon concurrent symposia delved into processes and nature of estuarine sedimentation, physiology of estuarine animals, and structural and dynamic properties of estuarine plankton.

A Thursday morning plenary session included discussions of nutrients and phyto-

plankton, the plankton of estuaries, and a panel discussion on benthos. The Thursday afternoon concurrent symposia covered the fields of biological aspects of specific estuaries, geochemistry of estuarine sediments, and integration of laboratory and field approaches to estuarine ecology. On Thursday evening the symposia considered the physical aspects of estuaries, estuarine microbiology, and ecological and evolutionary aspects of estuarine benthos.

Concurrent symposia on Friday morning included a second session on processes and nature of estuarine sedimentation, as well as discussions on the role of organic detritus in estuaries, and estuarine pollution.

The concluding Friday afternoon plenary session yielded interesting observations on the role of man in estuarine processes, nekton—its role in estuarine ecology, and the estuarine ecosystem.

Six manufacturers displayed a wide variety of their newest instruments designed for estuarine research.

Papers presented during the conference will be published.—WILLIAM W. ANDERSON, *U.S. Bureau of Commercial Fisheries, Biological Laboratory, Brunswick, Georgia.*

the water had been filtered. From these experiments it seems clear that the abundance of fish and invertebrates in shallow bays does not necessarily imply that salinity, temperature, or food are the factors that attract them. On the other hand, it is clear that these factors will be very important in determining growth and survival.

From the above experiments we can only say that the animals apparently prefer bay water. We do not know how they reach that habitat. It might be that the organic compounds act only as a stimulus and that there are other factors such as currents which help in guiding or transporting animals toward the mainland bays.

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Equalant II, a Mid-Summer "Photograph" of the Oceanographic Conditions, Tropical Atlantic Ocean

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Abstract

Scientists aboard 12 vessels from 8 nations participated in EQUALANT II, a quasi-synoptic oceanographic study of the waters of the tropical Atlantic. A similar, multiple vessel survey (EQUALANT I) was completed during February-March, 1963. These two surveys, designated as the International Cooperative Investigations of the Tropical Atlantic (ICITA), were coordinated by UNESCO's Intergovernmental Oceanographic Commission. The program of observations and samples, common to each vessel, included temperature, salinity, oxygen, and inorganic phosphate (surface to bottom), daily measurements of primary productivity, zooplankton tows, and routine bathythermograph, meteorological and sea surface radiation observations.

The two 15-day, multiple vessel surveys, EQUALANTS I and II, were planned so that the resulting data could be used to develop a "photograph" of the major winter and summer, surface and subsurface circulation features and the associated distribution of properties, of the rates of primary productivity in the surface waters (to the depth of the one percent fraction of incident radiation) and of the volumes and composition of the zooplankton (surface to top of the thermocline).

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Reprint from Proceedings of the Gulf and Caribbean Fisheries
Institute, Sixteenth Annual Session, November 1963,
p. 142-143, May 1964.

The ICITA data and atlases, both to be prepared for publication by the National Oceanographic Data Center, will be used during the planning and scheduling of future, more detailed, oceanographic, marine biological, and fishery investigations in the waters of the tropical Atlantic ocean.

Fishing Methods Developed for Small Boats

D. W. WILES
Fisheries Officer
Barbados, West Indies

SMALL BOATS play a most important part in many fisheries of the world. Although some of the methods used for the capture of fish from small boats may be considered primitive, many fishermen may find some interest in what is done in other parts of the world.

Line Fishing

First let us deal with line fishing as this must be one of the most important fishing methods of the small boat fishermen.

Today there is a choice of hemp, cotton, nylon, Dacron, and wire.

After our experiments, nylon monofilament lines of several breaking strengths have been widely accepted over the old hemp line by the entire local fishing fleet. As a trolling line the nylon can be much finer, is less visible in the water, and as a result more fish are landed. It is estimated that our dolphin (*Coryphaena*) fishery has been increased 33 1/3% since the introduction of nylon lines. Wire line has played an important part in the capture of wahoo. Again it is suspected that the fine wire is the reason for the successes over the hemp line, and the wire line sinks deeper than the nylon. Wire lines are quite easily handled, either with gloves, or on a rod, but commercial fishermen prefer hand lines.

It has been found that one person can handle a 40-50 pound wahoo on a wire line, provided the line is hauled while it rests on the gunwale of the vessel. When the wire is lifted off the gunwale the fish is likely to fight or call for line which can be very awkward. Small boats manned by one or two men often fish three lines from a boat with an 8- to 8 1/2-foot beam. The center line is a wire line, with two nylon lines on the beams, or it may be one nylon line in the center with two wire lines on the beams. This method avoids entangling the lines when turning the vessel. Outriggers and weights of different sizes may be used with advantage.

With crews of one or two persons fishing from a boat, the lines are attached to a rubber harness and the line is not disturbed by the crew until the rubber harness is good and properly stretched. The rubber being more sensitive than a person's reflexes does not permit a slipping line, especially unlucky if a wahoo has struck, as the hook must be set before the fish is allowed any run.

Lines are also used in a number of ways for the capture of fish which swim at depths, and recently we have introduced to the industry a miniature long line of just five hooks for use from a small boat. This method of fishing takes place from a drifting boat, during a flying fish operation. A heavy nylon line

Made in United States of America

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**Age, Growth, Maturity, and Sex Composition of the American Smelt,
Osmerus mordax (Mitchill), of Western Lake Superior**

MERRYLL M. BAILEY

Age, Growth, Maturity, and Sex Composition of the American Smelt, *Osmerus mordax* (Mitchill), of Western Lake Superior

MERRYLL M. BAILEY

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ABSTRACT

This study is based on 4,561 smelt collected in Chequamegon Bay, the Apostle Islands, the Brule River, and Superior Harbor, all in western Lake Superior. Commercial production in the Great Lakes (U. S. and Canada combined) reached a peak of nearly 16 million pounds in 1960. Production in Lake Superior has generally been small but increased during the 1950's to reach 948,000 pounds in 1960.

All 0-group and spring 1-group smelt had scales with sufficient sculpturing to permit detection of the first annulus. Annulus formation began after 6 June in 1960. In 1961, all smelt had completed the annulus by 24 August. The body-scale relation is a straight line with an intercept of -0.9 inch on the axis of fish length.

The weight of western Lake Superior smelt increased as the 2.952 power of the length. A large range of length in each age group and resulting overlap of age-groups II-VI made length a poor index of age. Female smelt grew faster than males after the second year and dominated strongly in age-groups IV-VII. Both sexes made their best annual growth in length (3.3 inches) during their second year of life; the largest weight increments (0.74 ounce, males; 0.85 ounce, females) came in the third year.

Best production from a commercial pound net in 1961 occurred when the sex ratios of spawning smelt were nearest 50:50. Spawning male smelt were consistently shorter than females and the average lengths of both sexes decreased as the spawning season progressed. Shortest mature smelt of each sex were 5.0 to 5.2 inches but the males are probably the first to reach 100 per cent maturity. All year-old smelt were immature. Among 2-year-old fish, 40.7 per cent of the males and 17.7 per cent of the females had reached maturity. All smelt more than 2 years old were mature. Ovaries of 10 smelt contained an average of 31,338 eggs for fish 7.3 to 8.8 inches long.

INTRODUCTION

The smelts (*Osmeridae*) are anadromous fishes of wide geographical distribution. They inhabit coasts of the Arctic, North Atlantic, and North Pacific Oceans, and thus form an irregular, interrupted, distributional belt that encircles the Northern Hemisphere (Kendall, 1927).

The American smelt, *Osmerus mordax* (Mitchill), common in the Great Lakes, is an introduced, landlocked form. Among the numerous plantings made in tributary or connecting waters of the upper Great Lakes in 1906-22, the 16,400,000 smelt eggs stocked in Crystal Lake, Benzie County, Michigan, in April 1912, appear to have provided the ancestors of the present populations (Van Oosten, 1937). The same paper by Van Oosten contains a detailed account of the subsequent dispersal of smelt in the Great Lakes through the mid-1930's.

In recent years, the smelt has become increasingly important in western Lake Superior,

as both a sport and commercial species. The present study deals with the size, age, growth and maturity of the species in this region.

Spawning-run smelt have been investigated extensively, but few studies have included samples obtained at other times of the year. This paper attempts to fill some of the voids in our knowledge. Smelt have long been a source of controversy. It is hoped that additional knowledge of their life history will contribute toward a better understanding of the present and future biological role and economic potential.

MATERIALS AND METHODS

This study is based on data from 4,561 smelt collected in Chequamegon Bay (near Ashland, Wisconsin), the Apostle Islands, the Brule River, and Superior Harbor (Table 1 and Figure 1). January-March samples were collected in 1- and 1½-inch-mesh (extension measure) nylon gill nets, 53 meshes deep and 2 feet long. The nets usually were fished on the bottom, but at times were suspended at va

TABLE 1.—Collections of smelt from western Lake Superior, 1958-62

Year and date of collections	Gear	Location	Number of fish
Jan.-5 Mar.	Gill nets	Chequamegon Bay	129
June-28 June	Otter trawl	Apostle Islands	30
Aug.	"	"	41
Sept.	"	"	32
Oct.	Gill nets	"	46
Apr.	Gill nets	Apostle Islands	23
May	Otter trawl	"	85
June-8 June	"	"	106
Aug.	"	"	17
Sept.	"	"	32
Oct.	"	"	24
Nov.	"	"	13
Feb.	Gill nets	Apostle Islands	25
Apr.	Shore seine	Chequamegon Bay	78
Apr.	Gill nets	Apostle Islands	118
Apr.	Otter trawl	"	79
May	"	Brule River	103
June	Gill nets	Apostle Islands	55
June-6 June	Otter trawl	"	179
July	Gill nets	"	48
July	Boom shocker	"	25
July	Otter trawl	"	145
Nov.	"	"	94
Feb.	Gill nets	Chequamegon Bay	10
Apr.-5 May	Pound net	Superior Harbor	2,337
July	Otter trawl	Apostle Islands	60
Aug.-24 Aug.	Gill nets	"	138
May	Otter trawl	Apostle Islands	102
June	"	"	220
Nov.	"	"	33
Dec.	"	"	134
Chequamegon Bay	—	—	217
Apostle Islands	—	—	1,904
Brule River	—	—	103
Superior Harbor	—	—	2,337
Grand total	—	—	4,561

depths under the ice. The remaining gill samples were collected in standard gangs (one nets of graded mesh, 1 to 5 inches, by 1-inch intervals) fished on the bottom, usually overnight. Most smelt were caught in the nets with the smaller meshes. The samples from standard gangs were collected in April-March from the U. S. Bureau of Commercial Fisheries research vessel *Siscowet*. Otter trawls fished by the *Siscowet* were a sub-balloon type with headrope lengths of 41 feet and mesh sizes of 2½ inches in the wings and body and ½ inch in the cod end. The shore seine fished during the spawning run was of ½-inch-mesh cotton twine, 6 feet deep and 25 feet long. The smelt from the Brule River were captured at a sea lamprey trap in a weir trap, 4 by 6 by 6 feet, constructed of ¾-inch-mesh (bar measurement) hardware cloth over a wooden frame. This

barrier is approximately 1 mile upstream from Lake Superior. Spawning-run samples from Superior Harbor were obtained from a commercial pound net, 7 feet deep, made of cotton twine of 1¼-inch mesh, shrunk to about 1-inch mesh through treatment with preservatives. The boom shocker consisted of two electrical wire paddles suspended from booms extending ahead of a 16-foot outboard-powered boat. Power for the shocker was supplied from a portable, 2.5-kw, 220-volt, 3-phase, a-c generator.

The effects of various kinds of selectivity were obvious. The gill nets (1- to 5-inch mesh) captured, almost exclusively, fish of age-group II or older. The shore seine, weir trap, and pound nets—fished only in the spring—sampled solely the spawning population. Since segregation by maturity precedes the spawning migration, immature specimens—all fish of age-group I and part of age-group II—were absent from these collections. The sex ratio, mean length, and age of these spawning-run samples varied, depending on the time within the spawning season. The otter trawls and boom shocker, fished at times other than the spawning period, appeared to be the least selective gears. Trawl collections usually included smelt of all sizes and age groups in presumably representative numbers. The boom shocker, fished only in shallow water, seemed to sample adequately the smelt in the waters fished.

The selectivity of the different types of sampling gear and segregation by sex, maturity, and size presented a problem as to which collections to include in the various phases of the study. Care was taken to select material according to need and applicability. When a situation required fish captured by more than one type of gear, comparisons were made to determine the validity of the combination of samples.

The total length of each fish (tip of head to tip of tail, lobes compressed) was determined to the nearest 0.1 inch. Fresh weights were determined to the nearest 0.1 ounce on a spring scale.

The sex of mature smelt was determined by gross inspection of the gonads, but immature fish of age-group II required microscopic

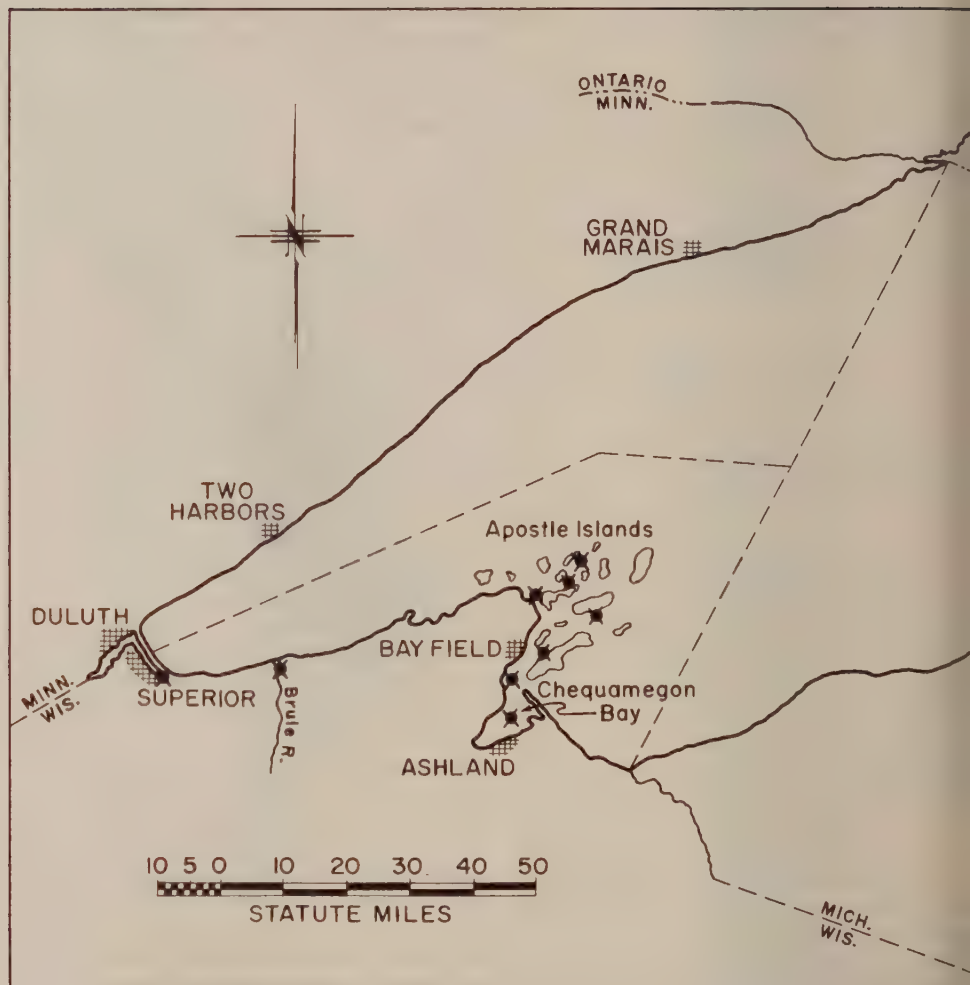


FIGURE 1.—Western Lake Superior. Dots with crosses represent sampling stations.

examination. Sex could not be determined with confidence for smelt of age-group 0 or of age-group I until near the end of the second growing season.

Scales were removed from the left side of the fish midway between the lateral line and the base of the dorsal fin. The scales were impressed in cellulose-acetate slides by a roller press (Smith, 1954) and were examined with a microprojector at the magnification $\times 83$. The body-scale relation was determined from scales taken from the key area described above. The diameters and growth fields within

annuli of the projected scales were measured in millimeters along the longitudinal axis of a line passing through the focus. Lengths and time of formation of each annulus were determined from a nomograph based on the body-scale relation.

Ages corresponding to the number of annuli are expressed in Roman numerals. Fish were moved to the next higher age group on 1 January of each year. A virtual annulus was accordingly assigned to the edge of the scale from that date until growth actually started

THE SMELT FISHERY

The commercial fishery for smelt in U. S. waters of the Great Lakes started in the Green Bay region of Lake Michigan in the early 1830's. This fishery for many years accounted for almost the entire U. S. output, and even now contributes the bulk of the catch. A second major fishery for smelt developed in Ontario waters of Lake Erie in the 1950's; this fishery now dominates Great Lakes production of the species. By 1960 the take of smelt in all Great Lakes waters, U. S. and Canadian, reached 16 million pounds.¹ No significant commercial landings of smelt from Lake Superior were reported until 1952 when 45,000 pounds were taken in U. S. waters (Table 2). The catch dropped to 21,000 pounds in 1953 but thereafter rose steadily to nearly a million pounds in 1960. Michigan's contribution to the U. S. total has been consistently small. Wisconsin supplied nearly all the catch in 1952-57, but when fishing began in Minnesota in 1958, that state assumed first place in smelt production. The Canadian output has been negligible throughout the entire period of record.

TABLE 2.—Commercial production of smelt (thousands of pounds) in Lake Superior, 1952-60

(Prior to 1952, the U. S. catch did not exceed 1,000 pounds in any single year (exception in 1938) and records of the Canadian production in the lake were not maintained. The data are from table 101, p. 155, of Baldwin and Saalfeld (1962).)

Year	United States				Canada Ontario	Grand total
	Michigan	Wisconsin	Minnesota	Total		
1952	— ¹	45	—	45	—	45
1953	— ¹	21	—	21	—	21
1954	3	22	—	25	— ¹	25
1955	2	72	—	74	— ¹	74
1956	4	114	—	118	3	121
1957	— ¹	138	—	138	1	139
1958	2	41	289	332	— ¹	332
1959	21	384	396	801	1	802
1960	29	334	584	947	1	948

¹ Less than 500 pounds.

Commercial catch statistics fail by a wide margin to reflect the true yield of smelt in the Great Lakes. Vast quantities are dipped or mined by sportsmen from the spring spawning runs. Van Oosten (1947) estimated that the early take by smelt dippers in the Green Bay area might be more than double the commercial catch. Similar situations exist in other smelt-producing areas in the Great Lakes.

SCALE OF THE SMELT

Characteristics of the annulus

An important phase of the study of the scales of smelt from western Lake Superior concerned the location and characteristics of the first year-mark. Because of the slow growth in cold northern waters, the possibility existed that some young-of-the-year smelt might complete the first growing season without forming scales. McKenzie (1958) observed 0-group smelt from the Miramichi River, New Brunswick, with scales in the form of unsculptured platelets and concluded, "The scales of late hatching smelt remain as small unridged plates during the first winter."

Materials relevant to this problem were obtained by collecting 0-group smelt as late as possible in the fall when, presumably, most first-year growth was completed, and 1-group fish in the spring, before second-year growth had started. Even the smallest smelt (1.5 inches long) in these collections (Table 3) had formed scales with sufficient sculpturing to permit detection of the first annulus. Every smelt from western Lake Superior, therefore, carries a detectable first annulus at the levels of first-year growth of 1959-60 and 1962. A decrease of growth rate, however, could invalidate this conclusion.

The 0.4-inch difference in average length between fish of fall (2.2 inches) and spring (2.6 inches) samples indicates possible con-

TABLE 3.—Length distribution of smelt near or at end of the first growing season 1959-60 and 1962

[As indicated by collections of age-group 0 in the fall and age-group 1 in the spring.]

Total length (inches)	October- November	April- May	Total length (inches)	October- November	April- May
1.5	7	—	2.7	5	16
1.6	4	—	2.8	4	11
1.7	11	—	2.9	4	13
1.8	10	1	3.0	6	16
1.9	7	3	3.1	5	10
2.0	16	9	3.2	—	2
2.1	7	4	3.3	2	4
2.2	12	10	3.4	—	1
2.3	5	12	3.5	1	3
2.4	11	19	3.6	—	—
2.5	10	22	3.7	—	1
2.6	4	23	—	—	—

Total number	131	181
Average length	2.2	2.6

¹ Statements on commercial smelt production in this section are based on statistics published by Baldwin and Saalfeld (1962).



FIGURE 2.—Tracing of magnified ($\times 83$) scale of I-group smelt at time of first annulus formation. Length of fish, 1.8 inches. Collected 13 July 1960.

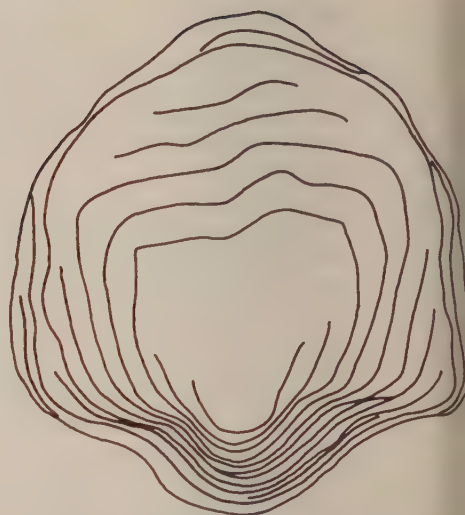


FIGURE 3.—Tracing of magnified ($\times 83$) scale of I-group smelt at time of first annulus formation. Length of fish, 3.0 inches. Collected 13 July 1960.

tinued growth after the fall collections were made. This likelihood of winter growth strengthens the conclusions that the first year-mark of the smelt is always recognizable since the amount of sculpturing on a scale increases with the length of the fish.

The smaller year-old smelt had scales with a relatively large focus and no completed circuli in the first growth field (Figure 2), whereas scales of the larger fish had a smaller focus and one to several completed circuli (Figure 3). Both types, however, exhibit clearly the diagnostic features of a gradual shortening of the horseshoe-shaped, incomplete circuli as growth slows in late season and a distinct cutting over of the first circulus

of the second growing season. Later annuli are easily recognizable. A growth field contains a series of complete circuli followed by a series of incomplete circuli that gradually shorten as growth slows. The first circulus that appears in the following growing season cuts across these shortened circuli.

Time of annulus formation

Materials suitable for the study of annulus formation were relatively scanty but still sufficient to bring out the trends. In 1960, no smelt of any age group collected 3 and 6 June had started the current-season growth (Table 4). In the next sample (6 July) only 39 per cent of II-group and no III-group spec-

TABLE 4.—Percentage of smelt, by age group, with completed annuli on various dates during the summer

Year and date	Age group									
	I		II		III		IV		V	
	Percentage with annuli	Number of fish	Percentage with annuli	Number of fish	Percentage with annuli	Number of fish	Percentage with annuli	Number of fish	Percentage with annuli	Number of fish
1960										
3 June	—	—	0.0	31	0.0	22	0.0	2	—	—
6 June	0.0	25	—	—	—	—	—	—	—	—
6 July	—	—	39.1	23	0.0	25	—	—	—	—
13 July	96.0	25	—	—	—	—	—	—	—	—
1961										
21 July	—	—	74.3	35	14.3	21	50.0	4	—	—
14 August	—	—	90.5	63	60.0	25	66.7	6	0.0	1
24 August	—	—	100.0	19	100.0	19	100.0	4	100.0	1

as gave evidence of a year-mark. On 13 July 1960, nearly all (96.0 per cent) of the I-group smelt (the only age group in the sample) had completed an annulus. None of the samples taken during the period of annulus formation in 1961 contained I-group smelt. Some fish of all age groups had begun the season's growth on 21 July 1961. In the August sample, 60.0 to 90.5 per cent of the I-groups II-IV had formed the annulus but no single V-group fish had not started to grow. All fish (age-groups II-V) had completed the annulus on 24 August.

The collection of the samples on various dates in two calendar years (1960 and 1961), and the fact that I-group and older smelt were never taken in the same collection, limit the conclusions that may be drawn. The data do not demonstrate, nevertheless, the general timing of annulus formation for smelt from western Lake Superior. Despite certain variation with year and possible annual differences, it appears that annulus formation starts near mid-June and is completed about the middle of August. Younger smelt form annuli earlier than do older ones. This phenomenon has been observed in other species by Hile (1941) and Smith (1956). Aside from exceptions among

the IV- and V-group smelt, which were represented by small numbers of fish, the percentage of smelt with new growth, in a single collection, decreased as age increased.

The shorter fish within an age group generally began the season's growth before the longer ones (Table 5). Smith (1956) found a similar situation in lake herring from Green Bay, Lake Michigan. In some age groups (the II and III groups of the 14 August 1961, sample), the current season's increment more than compensated the original difference in average length between the smaller and larger individuals.

Body-scale relation

Average fish lengths and scale diameters of 582 western Lake Superior smelt, by 0.3-inch intervals of length, were used to determine the body-scale relation (Table 6). Since some length intervals had large numbers of individuals, not all of the fish in each collection were used. A plot of the average fish lengths against the average scale diameters indicated the data were best described by a straight line (Figure 4). The equation for the line fitted by least squares is:

$$L = -0.911 + 0.035 S,$$

where L = total length of fish (inches),
and S = scale diameter (millimeters, $\times 83$).

For calculation, the intercept was rounded to -0.9 inch. All calculations of length from scale measurements were made nomographically.

TABLE 5.—Relation between total length of smelt and onset of new growth

Based on samples collected during period of annulus formation. Includes only age groups containing more than five fish, both with and without the new annulus.]

Date, age, and scale margin	Number of fish	Length (inches) before growth started ¹	Length (inches) at capture	Increment of new growth
July				
I-group II				
Not growing	14	6.39	6.39	0.00
Growing	9	5.72	5.91	0.19
Difference	—	0.67	0.48	—
14 August				
I-group II				
Not growing	9	5.90	5.90	0.00
Growing	26	5.60	5.91	0.31
Difference	—	0.30	-0.01	—
24 August				
I-group II				
Not growing	6	6.35	6.35	0.00
Growing	57	5.99	6.45	0.46
Difference	—	0.36	-0.10	—
13 September				
I-group III				
Not growing	10	7.38	7.38	0.00
Growing	15	7.34	7.51	0.17
Difference	—	0.04	-0.13	—

For fish without the annulus, this length is identical to length at capture; for fish with completed annuli, the length at annulus formation was computed from scale measurements.

TABLE 6.—Relation between total length of fish and magnified ($\times 83$) scale diameter of smelt from western Lake Superior

Number of fish	Average length (inches)	Average scale diameter ¹ (millimeters)	Number of fish	Average length (inches)	Average scale diameter ¹ (millimeters)
8	3.0	104	33	7.2	231
8	3.3	113	39	7.5	244
9	3.6	127	33	7.8	248
3	3.8	132	39	8.1	257
3	4.9	177	33	8.4	263
13	5.1	177	22	8.7	279
19	5.4	180	29	9.0	281
39	5.7	187	27	9.3	287
39	6.0	202	38	9.6	291
39	6.3	205	31	9.9	314
30	6.6	214	26	10.2	300
22	6.9	222	—	—	—

¹ Mean for fish within a 0.3-inch length interval.

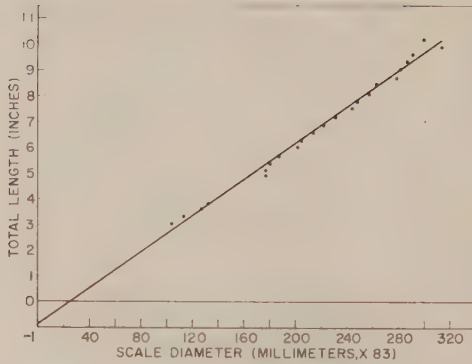


FIGURE 4.—Relation between total length of fish and magnified ($\times 83$) scale diameter for smelt from western Lake Superior. The dots represent the empirical data; the line is a graph of the equation given in the text.

LENGTH-WEIGHT RELATION

Preliminary examinations of length-weight data revealed no differences by sex, maturity, or state of gonads, and only one seasonal difference. Smelt of a given length captured during the winter (January–March) were consistently heavier than fish taken at other times of the year, including ripe smelt caught just before and during the spawning season. Periods of such prime condition in advance of spawning have been established for the coregonid species, *Coregonus* [*Leucichthys*] *kyi* (Deason and Hile, 1947) and *Coregonus clupeaformis* (Van Oosten and Hile, 1949).

The general length-weight relation was established, therefore, from all samples, regardless of sex, state of maturity, or time of collection (Table 7). I considered it unnecessary to use more than 40 fish to determine the mean values for any single interval, but when this restriction was imposed, some smelt from each season of the year were included. The averages for intervals represented by fewer than 40 smelt are based on all fish available regardless of time of collection.

The general length-weight equation, determined by fitting a straight line to the logarithms of length and weight, was:

$$\log W = -2.57962 + 2.95233 \log L,$$

where W = weight in ounces,
and L = total length in inches.

TABLE 7.—Length-weight relation of smelt from western Lake Superior

[The lengths and empirical weights are the true averages of fish in 0.3-inch groups; the calculated weights were computed from the equations given in the text.]

Number of fish	Average total length (inches)	Weight (ounces)		Number of fish	Average total length (inches)	Weight (ounces)	
		Empir-	Calcu-			Empir-	Calcu-
1	3.0	0.1	0.1	34	7.8	1.7	1.6
3	3.2	0.1	0.1	40	8.1	2.0	1.8
2	3.6	0.2	0.2	40	8.4	2.2	2.0
1	3.9	0.3	0.2	27	8.7	2.4	2.3
3	4.9	0.3	0.4	34	9.0	2.7	2.5
13	5.1	0.5	0.5	30	9.3	3.0	2.7
19	5.4	0.5	0.6	40	9.6	3.2	3.0
40	5.7	0.6	0.6	31	9.9	3.3	3.3
40	6.0	0.7	0.8	26	10.2	3.6	3.6
40	6.3	0.8	0.9	14	10.5	4.0	3.9
30	6.6	0.9	1.0	8	10.8	4.2	4.3
22	6.9	1.0	1.1	1	11.0	4.2	4.5
33	7.2	1.3	1.3	2	11.4	4.7	4.9
40	7.5	1.5	1.5	—	—	—	—

The weights computed for the mean lengths of fish in each length group are the basis of the curve in Figure 5.

The empirical and the calculated weights (Table 7) agreed reasonably well. The largest weight discrepancies (0.3 ounce) were at 9.

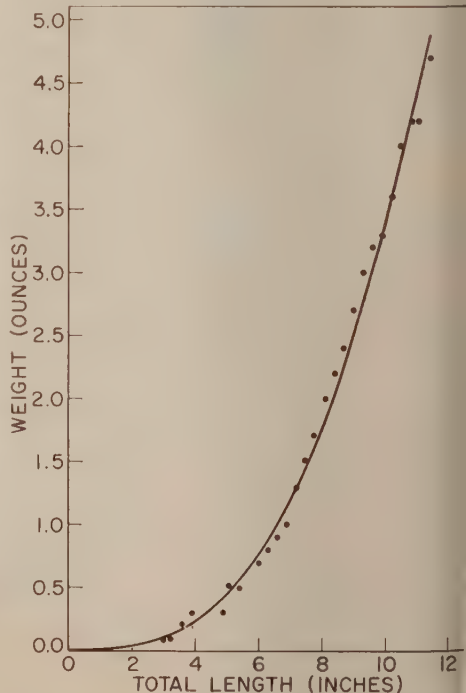


FIGURE 5.—Length-weight relation of smelt from western Lake Superior. The curve represents the calculated weights and the dots the empirical weights.

TABLE 8.—Average total lengths and weights of the age groups of smelt from western Lake Superior collected in the winter and spring of 1958-60

Male			Female		
Number of fish	Length (inches)	Weight (ounces)	Number of fish	Length (inches)	Weight (ounces)
181 ¹	2.6	—	181 ¹	2.6	—
136	6.0	0.7	63	5.9	0.7
45	7.3	1.4	64	7.7	1.7
8	7.9	1.9	84	8.7	2.5
3	8.6	2.3	35	9.4	3.2
—	—	—	9	9.8	3.8

Sexes combined for age-group I; weights were not determined.

11.0 inches. The maximum deviation at lengths below 8.1 inches was 0.1 ounce; all other discrepancies (0.2 or 0.3 ounce) were among the longer fish (8.4-11.4 inches).

LENGTH AND WEIGHT OF THE AGE GROUPS

The average total lengths and average weights of the age groups at capture (Table 8) are based on records for fish taken during the winter (presumably after completion of the season's growth) and in the spring (prior to onset of new growth). Annual differences in average size of smelt in the different age groups were so small that records for 1958-60 have been combined. Because more discriminating data are given in later sections on calculated length and weight, discussion is limited to general trends of increase in size with age and to comments on sex differences in growth.

Inasmuch as sex could not be determined for I-group smelt and most of these small fish (average length 2.6 inches) could not be weighed on a scale calibrated by 0.1 ounce, Table 8 gives only the mean length for the combined sexes of this age group. Mean lengths of the sexes most probably differed little at the end of the first year; the average length and weight of II-group males and females were nearly identical (males, 6.0 inches; females, 5.9 inches; both sexes 0.7 ounce). The average length of III-group males (7.7 inches) was 0.4 inch longer than that of males (7.3 inches). The females continued to add to this advantage through age-group V when their average length (9.4 inches) was 0.8 inch greater than that for males (8.6 inches). The mean weight of the

TABLE 9.—Length distribution of the age groups of smelt from western Lake Superior

[Based on actual length for fish that had not started current season's growth or on calculated length at last annulus for fish that had started current season's growth; beyond age-group I, fish without record of sex have been excluded.]

Length interval (inches)	Age-group and sex										
	I ¹		II		III		IV		V		VI
	M	F	M	F	M	F	M	F	M	F	F
1.5-1.9	5	—	—	—	—	—	—	—	—	—	—
2.0-2.4	54	—	—	—	—	—	—	—	—	—	—
2.5-2.9	85	—	—	—	—	—	—	—	—	—	—
3.0-3.4	33	—	—	—	—	—	—	—	—	—	—
3.5-3.9	4	—	—	—	—	—	—	—	—	—	—
4.0-4.4	—	—	—	—	—	—	—	—	—	—	—
4.5-4.9	—	—	—	3	—	—	—	—	—	—	—
5.0-5.4	—	11	13	—	—	—	—	—	—	—	—
5.5-5.9	—	46	33	—	—	—	—	—	—	—	—
6.0-6.4	—	75	32	3	1	—	—	—	—	—	—
6.5-6.9	—	10	19	11	10	—	—	—	—	—	—
7.0-7.4	—	2	2	14	32	1	2	—	—	—	—
7.5-7.9	—	—	—	14	39	5	6	—	—	—	—
8.0-8.4	—	—	1	6	21	4	29	1	2	1	—
8.5-8.9	—	—	—	2	6	—	31	1	5	—	—
9.0-9.4	—	—	—	—	—	—	22	1	14	—	—
9.5-9.9	—	—	—	—	—	—	6	—	8	3	—
10.0-10.4	—	—	—	—	—	—	—	—	5	4	—
10.5-10.9	—	—	—	—	—	—	1	—	1	1	—
11.0-11.4	—	—	—	—	—	—	—	—	1	—	—
Number of fish	181	144	103	50	109	10	97	3	36	9	—
Average length	2.6	6.0	6.0	7.3	7.6	7.9	8.7	8.6	9.4	9.8	—

¹ Sex not determined; M, male; F, female.

III-group females (1.7 ounces) was 0.3 ounce greater than that of males (1.4 ounces). Female smelt became progressively the heavier each year through age-group V where their average weight (3.2 ounces) was 0.9 ounce more than that for males (2.3 ounces). No VI-group males were taken; VI-group females were 9.8 inches long and weighed 3.8 ounces.

LENGTH DISTRIBUTION OF THE AGE GROUPS

The length distribution of the age groups of smelt from western Lake Superior (Table 9) are based on length at capture if new growth had not yet started or on the calculated lengths at the last annulus. Sex could not be determined for age-group I, but distributions for other age groups are by sex.

The length distribution of age-group I did not overlap that of age-group II of either males or females. The distribution of II-group male smelt overlapped the III group by 1.5 inches, and the III group completely overlapped age-group IV. The range in length for individual age groups (I-V) varied from 1.5 to 3.0 inches. Distributions of II-, III-, and IV-group female smelt overlapped from 2.0 to 3.0 inches. The range of age groups represented by 36 or more females (II-V) was 3.0 to 4.0

inches. The extensive overlap of the length distributions of female smelt caused the 0.5-inch length intervals to include fish of several ages. All intervals between 6.0 and 10.9 inches included at least two age groups, and five age groups (II-VI) were represented at 8.0-8.4 inches. With the exception of age-group I, length is a poor index of age for smelt of western Lake Superior.

CALCULATED GROWTH

Growth in length

The calculated lengths for samples from Chequamegon Bay, the Apostle Islands, and Superior Harbor exhibited no differences with location, gear, and date of capture. Calculated lengths for male and female smelt of western Lake Superior were significantly different beyond the second year (Tables 10 and 11).

TABLE 10.—*Calculated total length at end of each year of life of each age group of male smelt from western Lake Superior and average growth for the combined age groups, 1958-61 collections combined*
[Fish without record of sex have been excluded.]

Age-group	Number of fish	Length (inches) at end of year				
		1	2	3	4	5
II	182	2.7	6.0	—	—	—
III	110	2.3	5.6	7.2	—	—
IV	11	2.5	6.0	7.3	7.9	—
V	3	3.3	5.7	6.8	8.2	8.6
Grand average calculated length		2.6	5.9	7.2	8.0	8.6
Increment of average		2.6	3.3	1.3	0.8	0.6
Grand average increment of length		2.6	3.3	1.6	0.8	0.4
Sum of average increment		2.6	5.9	7.5	8.3	8.7

TABLE 11.—*Calculated total length at end of each year of life of each age group of female smelt from western Lake Superior and average growth for the combined age groups, 1958-61 collections combined*
[Fish without record of sex have been excluded.]

Age-group	Number of fish	Length (inches) at end of year						
		1	2	3	4	5	6	7
II	125	2.6	6.0	—	—	—	—	—
III	146	2.3	5.7	7.5	—	—	—	—
IV	110	2.7	6.0	7.7	8.7	—	—	—
V	36	2.9	6.0	7.7	8.8	9.4	—	—
VI	10	2.8	5.9	7.6	8.6	9.5	9.9	—
VII	1	2.3	5.5	8.1	9.3	10.7	11.7	12.2
Grand average calculated length		2.6	5.9	7.6	8.7	9.4	10.1	12.2
Increment average		2.6	3.3	1.7	1.1	0.7	0.7	2.1
Grand average increment of length		2.6	3.3	1.8	1.0	0.7	0.5	0.5
Sum of average increment		2.6	5.9	7.7	8.7	9.4	9.9	10.4

The calculated lengths exhibited no clear trends of systematic change with increase in age of the fish on which the calculations were based. The discrepancies among calculated growth histories of the age groups were randomly distributed. Some of these discrepancies may reflect true differences in growth, but those in the older age groups (IV- and V-group males; VI- and VII-group females) can be attributed mostly to small numbers of fish.

The estimates of general growth in length at the bottom of Tables 10 and 11 were derived by two methods. One estimate is based on the grand average calculated lengths and the other on the summation of the grand average increments of calculated length. With the exception of the seventh year (the collection contained a single VII-group female) the two methods gave similar results. The summation of the average increments were chosen for the preparation of Figure 6, because they avoid the irregularities caused by successive dropping out of age groups.

The calculated lengths of the sexes were the same at the end of the first and second years of life (2.6 and 5.9 inches). Female smelt were 0.2 inch longer than males at the end of the third year of life (7.7 and 7.2 inches); this advantage increased to 0.4 inch at the end of the fourth and 0.7 inch at the end of the fifth year. No VI- or VII-group males were caught. This difference in growth of the sexes of Great Lakes smelt has also been demonstrated by: Van Oosten (1947) in Green Bay, Lake Michigan; Baldwin (1950) in South Bay, Lake Huron; and Hale (1960) in western Lake Superior.

The low representation of male smelt in the older age groups gives strong evidence of differential mortality of the sexes. Samples used in age determination were obtained from gear presumably capable of capturing both male and female smelt of age-group III and older. Females, however, were taken in far greater numbers than males. Selective destruction in both the commercial and the sport fishery may have contributed to the scarcity of male in the older age groups. A large portion of the annual smelt catch is taken during the period of the spring spawning run dominated by males (see section on sex, length, and age).

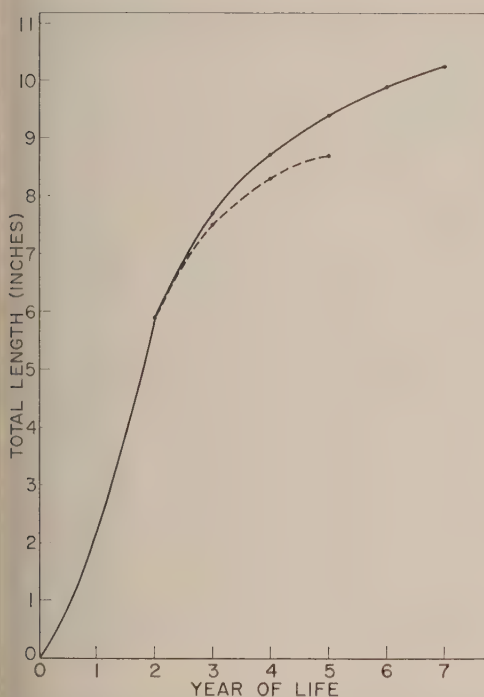


FIGURE 6.—General growth in length of male (broken line) and female (solid line) smelt from western Lake Superior. Growth of sexes was identical through the first 2 years of life.

composition of the 1961 spawning run in Superior Harbor). During the latter part of the run when females become plentiful, the markets are usually so glutted that fishing effort, both commercial and sport, is reduced.

Both sexes of western Lake Superior smelt made their greatest annual growth in length (3.3 inches) during the second year of life. Beyond the second year the increments decreased from 1.8 inches (females) and 1.6 inches (males) in the third year, to 0.4 inch for males in the fifth year and 0.5 inch for females in the sixth and seventh years.

The identical values (2.6 inches) of the average empirical length of the 181 I-group smelt captured in April and May of 1959–60 and 1962 (see section on the characteristics of the annulus), and the grand average calculated length at the end of the first year of life (bottom of Tables 10 and 11), support the view that the first annulus can be located accurately.

TABLE 12.—Calculated growth in weight of smelt from western Lake Superior

[Weights are computed from the general length–weight equation and correspond to the sum of the average increments of length at the end of each year of life.]

Year of life	Male		Female	
	Calculated weight (ounces)	Increment	Calculated weight (ounces)	Increment
1	0.06	0.06	0.06	0.06
2	0.72	0.66	0.72	0.66
3	1.46	0.74	1.57	0.85
4	1.96	0.50	2.26	0.69
5	2.26	0.30	2.84	0.58
6	—	—	3.30	0.46
7	—	—	3.82	0.52

Growth in weight

The calculated growth in weight of western Lake Superior smelt (Table 12) was determined by applying the length–weight equation, given previously, to the calculated lengths (sum of the average increments) at the end of each year of life (bottom lines of Tables 10 and 11).

Because of the equal growth in length of the sexes, the calculated weights of male and female smelt were the same at the end of the first (0.06 ounce) and second (0.72 ounce) years of life. At the end of the third year, the weight of females (1.57 ounces) exceeded that of males (1.46 ounces). This advantage increased progressively through the fifth year (Figure 7) when the calculated weight for female smelt (2.84 ounces) was 0.58 ounce greater than that of males (2.26 ounces). No males older than the V group were captured. The females reached 3.30 ounces in 6 years and 3.82 ounces in 7.

Both sexes had their best growth in weight during the third year (0.74 ounce for males and 0.85 ounce for females) despite the fact that the greatest annual increments of length were attained during the second year. Annual weight increments for male smelt declined to 0.50 ounce in the fourth year and 0.30 ounce in the fifth; increments for females decreased to 0.69 ounce in the fourth year and fell within the limits of 0.46 and 0.58 ounce in the fifth through seventh years of life.

SEX, LENGTH, AND AGE COMPOSITION OF THE 1961 SPAWNING RUN IN SUPERIOR HARBOR

Daily samples of smelt were collected during the 1961 spring spawning run from a com-

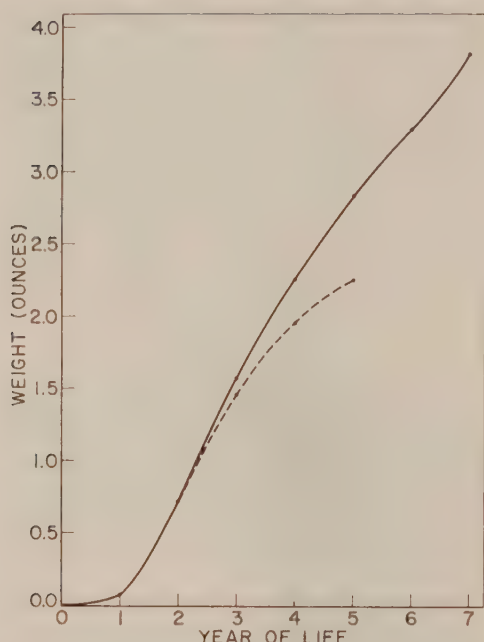


FIGURE 7.—General growth in weight of male (broken line) and female (solid line) smelt from western Lake Superior. Weights were computed from the general length-weight equation and correspond to the average calculated lengths (sum of the average increments). Growth in weight of sexes was identical through first 2 years of life.

mercial pound net in Superior Harbor at the extreme western end of Lake Superior. Data on length and sex were recorded for 2,337 fish collected from 19 April through 5 May 1961. On 3 days (19 April, 24 April, and 2 May) scale samples were taken from a total of 176 fish.

Males dominated the spawning population at the start of the run, the sex ratio was near 50:50 during the peak and females were numerous toward the end (Table 13). Daily production from the sample pound net (field records of the Wisconsin Conservation Department) was highest when the sex ratio was nearest 50:50 (28 April–2 May). A lesser production peak (23–25 April) demonstrates, however, that the catch can be relatively high when one sex is strongly dominant.

Male smelt were consistently smaller than females throughout the sampling period; the daily differences in average length ranged

TABLE 13.—Average daily lengths, sex composition and production of spawning smelt from Superior Harbor, 1961

Date	Males		Females		Percentage females	Production ¹ (hundreds of pounds)
	Number of fish	Average total length (inches)	Number of fish	Average total length (inches)		
April						
17	—	—	—	—	—	17.6
18	—	—	—	—	—	7.2
19	38	6.8	15	7.9	28.3	13.6
20	75	6.6	22	7.0	22.7	6.4
21	125	6.8	24	7.3	16.1	10.4
22	105	6.6	29	7.1	21.6	7.2
23	—	—	—	—	—	28.0
24	138	6.9	38	7.2	21.6	33.6
25	187	6.7	22	7.1	10.5	20.8
26	115	6.7	32	6.8	21.8	12.8
27	129	6.6	73	7.1	36.1	12.8
28	89	6.4	78	7.1	46.7	48.0
29	74	6.5	87	6.8	54.0	36.0
30	—	—	—	—	—	42.4
May						
1	109	6.3	95	7.0	46.6	33.6
2	87	6.4	109	6.9	55.6	32.5
3	52	6.5	117	6.8	69.2	5.6
4	43	6.2	100	6.4	70.0	2.4
5	20	6.1	110	6.7	84.6	1.6
Total or average	1,386	6.6	951	6.9	40.7	19.6

¹ Production for the pound net from which the sample were collected.

from 1.1 inches on 19 April to 0.1 on 2 April. The grand average length for all female (6.9 inches) was 0.3 inch greater than that of males (6.6 inches).

The mean lengths of both sexes decreased irregularly as the spawning season progressed (Figure 8). The average length of males in daily samples equaled (3 days) or exceeded

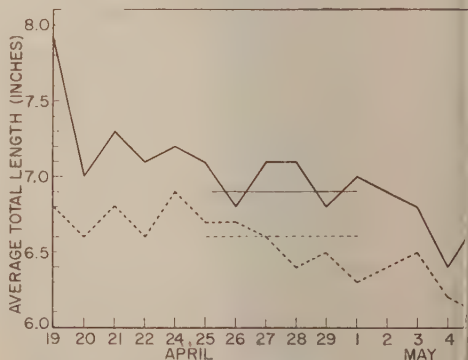


FIGURE 8.—Average total lengths of male (broken line) and female (solid line) spawning smelt from Superior Harbor, 1961. The two horizontal lines represent the average lengths for the entire spawning period.

TABLE 14. *Age distribution and average age and total length (inches) of spawning smelt taken in Superior Harbor, 1961*

Date and item	Age-group					Average age (years) and length ¹ (inches)
	II	III	IV	VI	VII	
Males						
19 April						
Number	12	25	—	—	—	2.7
Length	6.1	7.1	—	—	—	6.8
24 April						
Number	2	26	—	—	—	2.9
Length	5.8	7.2	—	—	—	7.1
2 May						
Number	25	10	1	—	—	2.3
Length	6.0	7.0	7.7	—	—	6.3
Combined collections						
Number	39	61	1	—	—	—
Length	6.0	7.1	7.7	—	—	—
Females						
19 April						
Number	2	8	3	1	1	3.5
Length	6.2	7.2	8.5	10.9	12.2	7.9
24 April						
Number	8	9	4	—	—	2.8
Length	6.3	7.3	8.5	—	—	7.2
2 May						
Number	14	20	5	—	—	2.8
Length	5.9	7.2	8.4	—	—	6.9
Combined collections						
Number	24	37	12	1	1	—
Length	6.1	7.2	8.5	10.9	12.2	—

¹ Average total length for fish from which scale samples were taken.

(5 days) the grand average length of 6.6 inches through 27 April, but was consistently below the grand average thereafter (7 days). The daily mean length of females fell below the grand average of 6.9 inches only 1 day through 28 April, and was higher the remaining 8 days; after 28 April, the daily mean length exceeded the grand average 1 day, equaled it 1 day, and was below it 4 days. A similar trend of decreasing length was observed by McKenzie (1958) in spawning-run smelt of the Miramichi River, New Brunswick.

Fluctuations in the average age of both sexes followed closely the changes in average length (right-hand column of Table 14). In the three possible comparisons of samples of males, each difference of mean length was accompanied by a difference in the same direction of mean age. The same held for two of three comparisons among samples of females. Only the collection of 2 May showed a 0.3-inch decrease in mean length (7.2 to 6.9 inches) while mean age remained at 2.8 years. It appears, then, that both average length and age of Superior Harbor smelt tend to decrease as the spawning season progresses.

Smelt of age-group III dominated the com-

bined samples of each sex in 1961 (60.4 per cent of the males and 49.3 per cent of the females). Age-group II followed (38.6 per cent of the males and 32.0 per cent of the females). The samples included also a single IV-group male (1.0 per cent) and 12 IV-group females (16.0 per cent). No male smelt were older than age-group IV, but the samples included one VI- and one VII-group female (1.3 per cent each).

The high percentage of spawning smelt of age-group III in 1961 does not agree with the findings of previous workers on the Great Lakes. The 1948 spawning population in South Bay, Lake Huron (Baldwin, 1950) and the 1954 run at Duluth in Lake Superior (Hale, 1960) were predominantly age-group II. Exceptional strength of the 1958 or weakness of the 1959 year class could account for the dominance of III-group fish in the 1961 spawning run at Superior Harbor. Unfortunately, materials are lacking for the determination of the relative year-class strength for these 2 years. On the other hand, if the percentage maturity (40.7 per cent of the males and 17.7 per cent of the females) for the potential II-group spawning smelt sampled in the late fall of 1962 (see next section) is truly representative, the findings here could well be expected.

SIZE AND AGE AT MATURITY

Trawl samples of western Lake Superior smelt were obtained during late November through mid-December 1962 for study of size and age at maturity. This particular time of the year was selected because gonad development was at a stage where sex could be determined in both mature and immature smelt of age-group I, and an apparently unsegregated sample of the population could be obtained.

All smelt shorter than 5.0 inches were immature. The shortest mature male was at 5.0–5.2 inches and all were mature at the 5.9- to 6.1-inch interval (Table 15). The shortest mature female was also at 5.0–5.2 inches, but data for the higher length intervals are scanty. Over 50 per cent maturity was reached at 5.6–5.8 inches, but the next interval (5.9–6.1 inches) contained no fish. Of the four females at 6.2–6.4 inches, all were mature, but at 6.5–

6.7 inches the single specimen was immature. Eleven female smelt 6.8 to 8.0 inches long were all mature. It appears, then, that the shortest mature smelt of each sex have about the same length (5.0–5.2 inches), but that the males are probably the first to reach 100 per cent maturity.

TABLE 15.—*Relation between length and sexual maturity of smelt from western Lake Superior*

[All fish shorter than 5.0 inches were immature; all fish longer than 6.7 inches were mature.]

Total length (inches)	Males			Females		
	Number immature	Number mature	Percentage mature	Number immature	Number mature	Percentage mature
5.0–5.2	10	1	9.1	20	1	4.8
5.3–5.5	9	1	10.0	10	4	28.6
5.6–5.8	3	9	75.0	4	5	55.6
5.9–6.1	—	10	100.0	—	—	—
6.2–6.4	—	4	100.0	—	4	100.0
6.5–6.7	—	1	100.0	1	—	0.0

All smelt were immature after one growing season and all were mature after three or more growing seasons. Of the fish that had completed two growing seasons, 22 of 54 (40.7 per cent) of the males were mature but only 11 of 62 (17.7 per cent) of the females had reached maturity. This estimate of percentage maturity of females may be somewhat low because of the seemingly small numbers of the longer, and presumably mature, 2-year fish. It is clear, nevertheless, that many western Lake Superior smelt do not reach maturity and spawn as members of age-group II.

FECUNDITY

Estimates of the number of eggs in 10 smelt ovaries collected on 21 February 1961, were made by the gravimetric or dry-weight method. The alcohol-preserved ovaries were separated thoroughly and as much tissue and other matter as possible removed from the eggs. The eggs were then dried at room temperature and the separating process continued throughout the drying period. After separation, a random sample of 2,000 eggs was counted from the entire ovary. Counting the dried eggs was extremely difficult due to their small size and tendency to stick together. Addition of a small amount of water, however, reduced these difficulties to a tolerable minimum. After the counting was completed, all

eggs were redried until a stable weight was attained. The 2,000-egg sample and the remainder of the eggs were then weighed separately on a milligram balance and the total number of eggs was estimated.

The average number of eggs per ovary for smelt 7.3 to 8.8 inches long of western Lake Superior was 31,338 and ranged from 21,534 to 40,894 (Table 16). No clear relationship exists between length or weight of fish and number of eggs per ovary. True, the 7.3-inch specimen contained somewhat fewer eggs (22,362) than the average, but the largest number of eggs (40,894) was from an 8.2-inch fish that weighed 2.2 ounces. An 8.5-inch smelt weighing 2.0 ounces, had the smallest number of eggs (21,534).

TABLE 16.—*Relation between the length of smelt from western Lake Superior and the number of eggs in the ovaries*

Total length (inches)	Number of fish	Average number of eggs per fish	Number of eggs per ounce of fish
7.3	1	22,362	14,908
8.1	5	30,705	14,215
8.2	1	40,894	18,588
8.3	1	36,078	16,399
8.5	1	21,534	10,767
8.8	1	38,983	14,993
Total or average	10	31,338	14,673

Egg diameters were measured by placing a few eggs on a microscope slide and then magnifying them ($\times 83$) with a microprojector. Images of egg diameters were measured for three to six eggs from each ovary by a millimeter ruler. Actual mean diameters of eggs from 10 smelt ovaries ranged from 0.71 to 0.99 mm and the grand average diameter was 0.86 mm. Length or weight of fish showed no relation to egg diameter.

Among the results from other fecundity studies, the estimates by Baldwin (1950) for Lake Huron and Van Oosten (1940) for Lake Michigan appear most nearly comparable to those of the present study. The means of 20,570 eggs for five Lake Huron smelt 5.5–8.1 inches long and 25,000 eggs for smelt 7.3–7.9 inches in length from Lake Michigan are in close agreement with the counts for smelt from western Lake Superior.

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James Ludack of the Wisconsin Conservation Department helped collect data. Stanley Sivertson, commercial fisherman, supplied the daily samples from pound nets in Superior Harbor. Ralph Hile reviewed the original manuscript. William L. Cristanelli prepared the figures.

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Retention of Radionuclides by the Atlantic
Croaker, *Micropogon undulatus*

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Whole-body retention of strontium-85, niobium-95, iron-59, cobalt-60, zinc-65, and indium-114 by croakers was determined following oral administration or intraperitoneal injection of each radioisotope. Retention of cobalt-60 was expressed as a single rate function representing a biological half-life of 31 days. Retention of the other radionuclide tested was expressed as multiple rate functions consisting of two components. The long-lived component of strontium-85 had a biological half-life of 138 days; niobium-95, 465 days; iron-59, 215 days; zinc-65, 138 days; and indium-114, 224 days. Comparisons were made between the biological half-life and the effective half-life of each radionuclide.

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Vol. 11, No. 2, p. 39, April 1964.

22. STUDIES OF OCEAN CURRENTS NEAR THE HAWAIIAN ISLANDS

Currents near the Hawaiian Islands are being studied by several methods, for their intrinsic interest to the physical oceanographer, and also because they are a fundamental influence on the marine ecology.

Since 1961, the currents have been studied by means of drift bottles and cards which were released by the research ship "Charles H. Gilbert." The pattern of reported returns suggests a seasonal change in both the speed and direction of the offshore current system. In the first half of the year, the current carries the drift cards and bottles at speeds of about 6 miles per day or less, and the flow has a pronounced northern component; later in the year the speeds increase to about 10 miles per day or more, and the direction of flow shifts toward the west or southwest.

Direct measurements of currents have been made by means of surface floats attached to parachutes opened some distance below the sea surface. These floats have been used to examine details of eddy flow downstream of the Islands, in an attempt to study the generation, duration, and the dissipation of eddies, which are important elements of the current pattern near the Hawaiian Islands.

Finally, data collected by observations at sea are used to calibrate a scale hydrodynamic model of the Hawaiian Islands, in which patterns of current flow can be studied and photographed in the laboratory, under controlled conditions.

RICHARD A. BARKLEY
U. S. Bureau of Commercial Fisheries

1964. /Abstract/ Proceedings of the Hawaiian Academy of Science.
39th Annual Meeting, 1963-1964, p. 25-26.

RICHARD A. BARKLEY
THE THEORETICAL EFFECTIVENESS OF
TOWED-NET SAMPLERS AS RELATED
TO SAMPLER SIZE AND TO
SWIMMING SPEED OF ORGANISMS

EXTRAIT DU JOURNAL DU CONSEIL INTERNATIONAL
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The Theoretical Effectiveness of Towed-Net Samplers as Related to Sampler Size and to Swimming Speed of Organisms

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Introduction

One of the vexing problems which confront the marine biologist is that of evaluating the effectiveness of towed nets as samplers of the marine biota; the obverse of this problem is that of designing towed nets to sample specific portions of the marine community. Studies of sampling effectiveness have thus far been based primarily upon statistical analysis of samples obtained in the field, often on an *a posteriori* basis; net design has been based upon past experience and trial and error. In the present analysis we shall depart from this pattern to consider, in a rather elementary way, the physical factors which ultimately limit a net's ability to catch a single organism. The results provide a basis for estimating the minimal effectiveness of existing towed nets and for improving net designs.

Method

Figure 1 shows the relationship which exists when a towed net approaches an individual organism. The organism is assumed to sense the oncoming net and to react to it by attempting to dodge. When it begins to react, the organism is located at point p , which is a distance x_0 ahead of the net and another distance r_0 away from the axis of motion of the net, which has a radius of R and is being towed at some speed U . The reaction of the organism carries it through the water at some speed u , in a direction which is at some angle θ to the net's axis of motion. As a result, the organism will either be outside or inside the rim of the net when the net catches up with it; if it is inside, it is assumed that the organism has been captured.

Since the objective of towed-net sampling is to obtain the maximum possible catch from the water column through which the net is towed, the net should be designed to minimize the effects of dodging; it will be seen that this can be

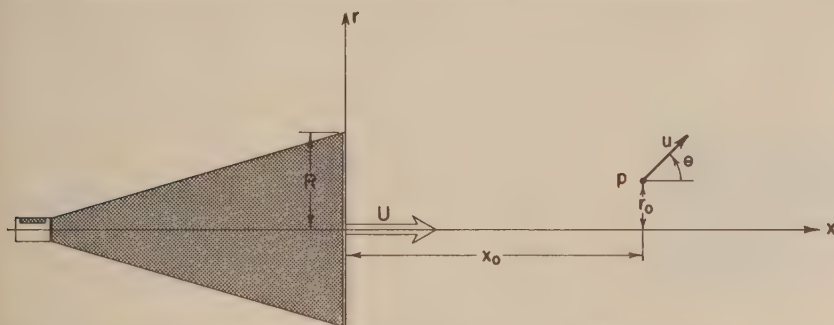


Figure 1. Coordinate system and notation used, showing conditions at the instant when the organism, at point p , begins to react to the presence of the net.
For full description see text.

done by making the radius of the net's opening as large as possible and by towing at the highest possible speed. However, these two conditions conflict, because with a given amount of power a large net cannot be towed as fast as a smaller one, owing to drag effects. The problem can be stated thus: what is the optimum size of a towed-net sampler; what are the characteristics of this optimum-size net in terms of its efficiency in capturing organisms which can attempt to dodge it; and how can these characteristics be improved?

The problem stated above has been subjected to a mathematical analysis. The analysis is given in the Appendix, while the argument on which the analysis is based and its results, which are of more immediate interest, are discussed in the body of this paper. For the sake of simplicity it will be assumed that the net allows all the water in its path to pass through its opening. In practice a correction may have to be made for the fact that the net may push some of this water aside, so that R represents the effective filtering radius of the net. This effective filtering radius would depend, *inter alia*, upon the shape of the net, its mesh and cordage sizes, and the speed of the tow. It could be determined by experiments in towing tanks or flumes.

Results

In the Appendix an equation is derived which gives the minimal escape velocity (u_e) relationships for an organism in terms of its reaction distance (x_0) and initial offset (r_0), as well as the speed (u) and direction (θ) of the organism and the speed (U) and radius (R) of the net. This relationship can be shown in a vector diagram, in which distances are proportional to speeds; Figure 2 shows such a diagram for each of two similar cases, together with schematic drawings showing the relative positions of the nets in each example. In Figure 2, examples A and B differ only in that in the first case the initial offset of the organism is zero, while in the second the initial offset is 25 cm; the values of the other constants are: radius of net $R = 100$ cm, reaction distance $x_0 = 250$ cm, speed of tow $U = 150$ cm/sec (2.9 knots). The escape velocity is proportional to the distance between the starting point of the organism, p , and the line u_e , which is the locus of the escape velocity vectors. Two cases of particular

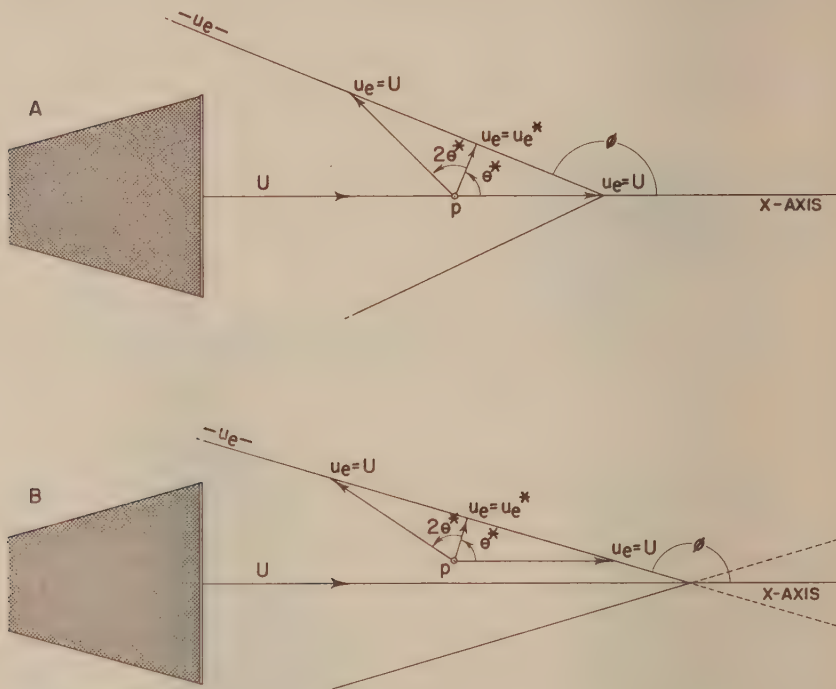


Figure 2. Escape velocity relationships for a net of 100 cm radius, moving at a speed of 150 cm/sec toward an organism which reacts at a distance of 250 cm. Initial offsets (r_0) of zero (example A) and 25 cm (example B). Escape velocity is proportional to the distance between point p and the line marked u_{e*} .

interest are shown explicitly as vectors: the cases where the escape velocity equals the towing speed ($u_e = U$) and the case where the escape velocity is at a minimum, that is, where the vector is perpendicular to the curve u_e . This minimum escape velocity will be referred to by the symbol u_{e*} . The angle corresponding to this minimum escape velocity is θ^* . It is worth noting that the escape velocity equals the velocity of the net when the organism swims parallel to the net's axis of motion ($\theta = 0$) or when it swims at an angle equal to $2\theta^*$; at intermediate angles the escape velocity is less than the speed of the net, and at larger angles it is greater than the towing speed.

For every set of values of R , U , x_0 and r_0 there is a minimum value of the escape velocity, u_{e*} . It is possible to use this value to determine the minimum effectiveness of a net already in use, or as a criterion for improved net designs; that net having the highest value of u_{e*} is desirable in that it has the highest threshold against escape by dodging. Equation 7 in the Appendix shows the way in which the minimum escape velocity varies with changes in the other variables in the problem; in general, the escape velocity increases proportionately with an increase in either the towing speed or the net radius, and decreases in proportion to increases in either the reaction distance or the initial offset of the organism.

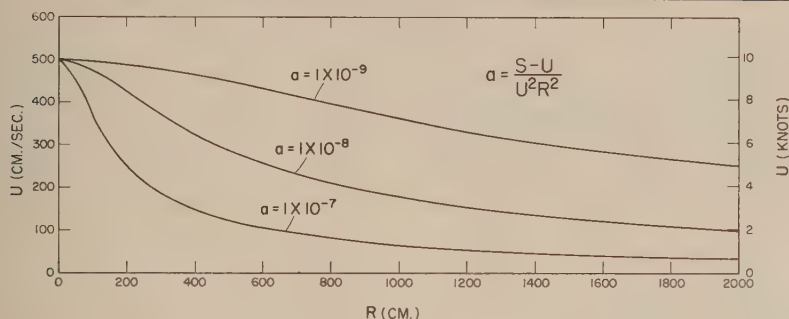


Figure 3. Assumed relationship between towing speed U and radius of net R , from equation (9) (Appendix), for three cases: Upper line, relatively powerful ship (or winch) or low-drag net design. Middle line, ship of medium power or medium-drag net design. Lower line, relatively low-powered ship or high-drag net design.

See Appendix for a full discussion.

This suggests that both U , the towing speed, and R , the radius of the net, should be increased to increase the effectiveness of the net. But there is a limit to the advantage to be gained from such increases, since the towing speed cannot be greater than the maximum speed of the ship or the winch which does the towing, and this speed is in turn dependent upon the drag of the net, which increases with an increase in the net's radius. Figure 3 shows the maximum towing speeds which would result from changes in the radius of a single net design, for ships or winches of three ranges of power, or for nets of high, medium, and low inherent drag with one ship or winch. The towing speed is dependent upon the maximum speed of ship or winch without the net (S), the speed with the net in the water (U), and the size of the net's opening (R); the relationship which is assumed to exist between these factors is discussed in the Appendix.

It is obvious from the relationship shown in Figure 3, with towing speed dropping off with increased radius of the net towed, together with the relationships in equations (5) and (7), in the Appendix, where catch effectiveness (as measured by the escape velocity) increases with an increase in R , that there must be some combination of speed of tow and size of net which yields the highest, or optimum, value of u_e^* , the minimum escape velocity. Figure 4 shows examples of such relationships for a vessel of medium power (middle curve in Figure 3, where $a = 1 \times 10^{-8}$) and various combinations of x_0 and r_0 . Each family of curves in Figure 4 shows the values of minimum escape velocity u_e^* as a function of net radius R for one value of r_0 and various values of x_0 . In each case it is evident that there is an optimum net radius such that u_e^* is at a maximum.

Two important conclusions are evident from the curves presented in Figure 4. First, the minimum escape velocities decrease rapidly as R decreases below the optimum values, so that it is most inefficient to reduce the net opening to low values, because the gain in speed of tow is more than offset by the ease with which the smaller net may be avoided. Second, the importance of minimizing the reaction distance x_0 is obvious; a net which cannot be detected ($x_0 \leq 0$) would have a minimum escape velocity equal to or greater than, the towing speed, while minimum escape velocities for nets detectable at 10 metres are

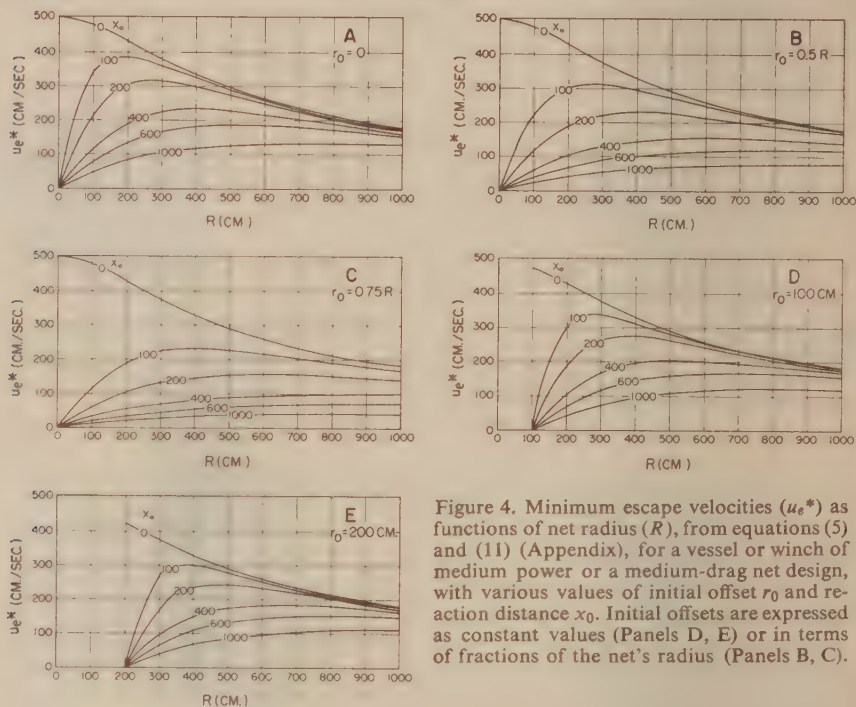


Figure 4. Minimum escape velocities (u_e^*) as functions of net radius (R), from equations (5) and (11) (Appendix), for a vessel or winch of medium power or a medium-drag net design, with various values of initial offset r_0 and reaction distance x_0 . Initial offsets are expressed as constant values (Panels D, E) or in terms of fractions of the net's radius (Panels B, C).

small fractions of the towing speed even at their optimum size, except under the most favourable conditions for extremely large nets.

Table 1 presents a comparison of the minimum escape velocities for nets of 50 cm radius (the well-known 1-metre net), 300 cm radius, and the optimum radius. It suggests that a net with 300 cm radius is several times more effective than the 50 cm net, and only slightly less effective than the optimum sizes, which tend toward completely unmanageable dimensions.

One final aspect of the present analysis deserves further consideration. In Figure 2 A, the locus of all values of the escape velocity u_e was presented as a line for one set of values for U , R , and x_0 , when r_0 equalled zero. If x_0 and r_0 remained unchanged, and only R were allowed to vary, a series of lines, similar to those of Figure 2A, loci of u_e , would result, one for each value of R . If these were arranged in sequence by increasing values of R , the result would be a surface representing the field of values for u_e for a series of similar nets of varying size. Figure 5 is an example of such a surface, together with a schematic drawing of the sampling nets to the same scale in isometric projection, showing the assumed physical relationship between the organism (at the origin $u_e = 0$ when $t = 0$) and various possible sizes of net. The constants used in calculations for Figure 5 were: $r_0 = 0$, $x_0 = 400$ cm, $S = 500$ cm/sec, and $a = 1 \times 10^{-8}$ cm³/sec. Isotachs (solid heavy curved lines in Figure 5) are shown as intersections of cylinders of radius 100, 200, 300, 400 and 500 cm/sec with the surface of u_e . The point on the dashed curve marked with an encircled x represents the maximum value of u_e^* for the surface depicted in the

Table 1

Minimum escape velocities for nets of various radii (50 cm, 300 cm, and optimum) as a function of reaction distance for various amounts of initial offset

Initial offset r_0	Reaction distance x_0	Minimum escape velocities u_e^*			R_{opt}
		50 cm	300 cm	Optimum	
0 cm	1,000 cm	25 cm/sec	110 cm/sec	135 cm/sec	(680) cm
	600	41	170	185	(525)
	400	62	225	235	(410)
	200	125	310	315	(275)
100 cm	1,000	0	75	120	(850)
	600	0	120	170	(660)
	400	0	170	200	(520)
	200	0	260	275	(390)
0.75 R	1,000	10	55	80	(> 1,000)
	600	20	90	120	(780)
	400	30	130	155	(600)
	200	60	220	230	(410)

figure. Figure 4A shows the same curve (in two dimensions) of u_e^* versus R , for $x_0 = 400$, as that shown in isometric projection on Figure 5. One most interesting relationship shown in Figure 5 is the range of values of u_e resulting from each of various values of the radius R . Considering only values of the angle θ between 0° and 90° we find, for example, that a net with radius 50 cm has a range of escape velocities from about 500 to 60 cm/sec, depending upon the value of θ , the direction in which the organism swims in attempting to escape. Similarly, at $R = 400$ cm, we observe that the escape velocity ranges from maximum values of 330 cm/sec at $\theta = 0^\circ$ and 90° , to 230 cm/sec at $\theta = 0^*$. Evidently the net with a radius of 400 cm is far less subject to the effects of changes in escape angle than is that with a radius of 50 cm, at least for the case where θ does not exceed 90° ; that is, in those cases where the avoidance reaction does not involve swimming toward the oncoming net. Presumably, then, the effectiveness of a net of 400 cm radius would be only slightly affected by varying behaviour patterns of organisms with respect to their choice of direction for dodging the oncoming net; its selectiveness would then be largely a function of swimming speed. Comparison of catches with nets of different radii may make it possible to estimate both swimming speed and preferential directions of dodging for a number of species of organisms.

Discussion

The analysis thus far has assumed a circular net opening and a speed of tow limited only by the power available for towing, and it has treated only the capture of single organisms. Clearly such an analysis cannot begin to elucidate all of the complex problems involved in sampling the marine biota with towed nets. It can only indicate the magnitude of the limiting physical factors involved in the sampling process, suggest means for avoiding inherently poor physical designs, and point the way toward fruitful avenues for research on towed nets.

Some extensions of the simple theory are obvious: a net of noncircular opening can be treated by redefining R to mean the least distance between the centre of the opening and the rim of the opening, and by substituting A , the

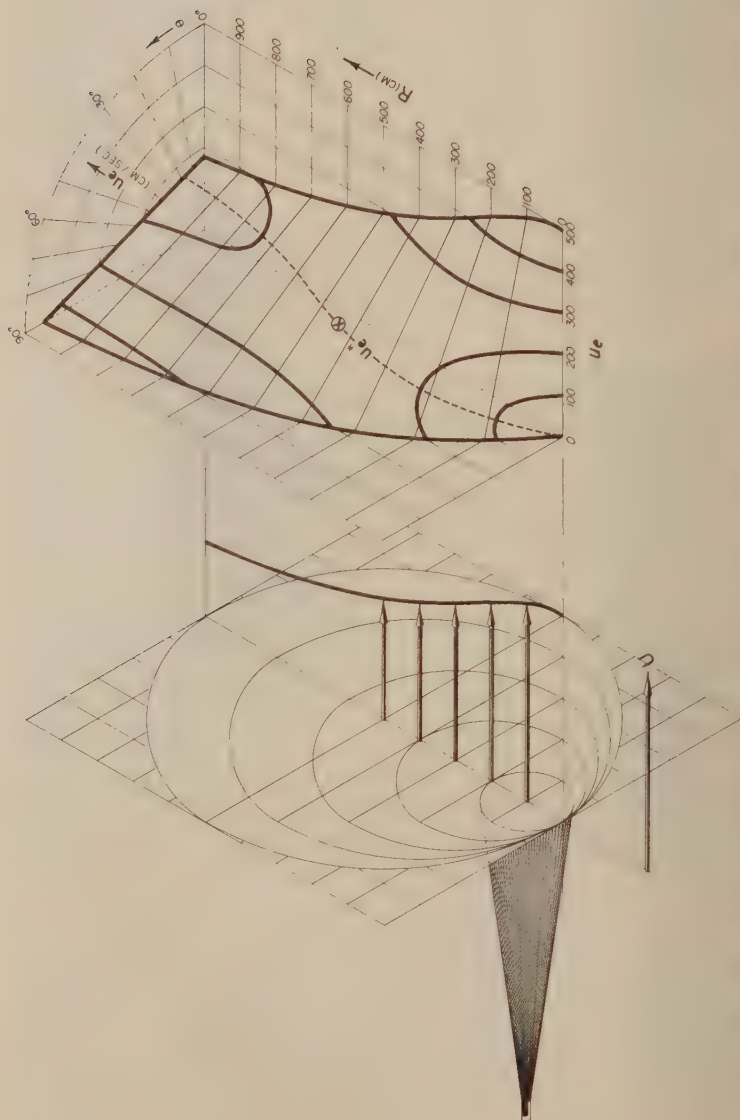


Figure 5. The field of escape velocities, as a function of escape angle θ , from equations (5) and (11) in the Appendix, for various sizes of one net design, together with a schematic drawing of sampling nets illustrating the physical relationship which is assumed to exist between the organism and various sizes of net. Escape velocity is proportional to the distance from the origin ($u_e = 0$) to the surface on which the isotachs (heavy curved lines) lie. For full description see text.

frontal area of the net, for R^2 in equation (9) in the Appendix. But this is a trivial substitution, because the frontal area of any net, regardless of shape, will vary as the square of the linear dimensions of the opening when the net design is scaled up or down in size.

The analysis might be extended to the case where the net is towed at less than the maximum possible speed. In this case the maxima in escape velocities as shown in Figure 4 would simply be truncated at the level where u_e^* is equal to the restricted towing speed.

A more fundamental extension of the theory would be that of considering a number of encounters instead of conditions for a single capture. This will require making assumptions about the distribution of organisms in the water. For example, it can be calculated that a randomly distributed population in the net's path would encounter the net in such a way that the initial offset r_0 would have an average value $\bar{r}_0$, equal to $\frac{R}{\sqrt{2}}$, because this is the radius of a circle whose area is one-half that of the net with an opening of radius R ; one-half of the organisms encountered would be found inside of $\bar{r}_0$, and one-half between $\bar{r}_0$ and R . This elementary result assumes, of course, that there is no interaction between the organisms.

By these and other means it should be possible to determine the minimum escape velocities of a variety of net designs. More immediate tests of the conclusions reached would require systematic comparative trials of nets, such as that reported for smaller nets by KÜNNE (1929 and 1933), but over wider ranges of net size. An example of intercomparison of larger nets similar in design but differing in size is ARON's (1962) recent survey of equipment used for sampling the larger plankton. ARON (1962) concludes that the Isaacs-Kidd midwater trawl appears to be the best all-around device available today for sampling the larger plankton and small nekton. It is reasonable to assume that this conclusion is at least in part due to the near-optimum size of the Isaacs-Kidd trawl, as well as its ease of handling.

In addition to simple changes in size, the analysis suggests that there is much to be gained by greatly decreasing the distance ahead of the net at which organisms begin to react to its approach, as by reducing its visibility or making it move more silently. This idea is by no means novel, but its quantitative value is made evident here for the first time.

Finally, one of the most significant conclusions reached is that nets of non-optimum size are relatively sensitive to the direction in which an organism moves in attempting to avoid the net. In the absence of such effects, a towed net would select its catch primarily on the basis of swimming speed. Elimination of swimming direction as an important variable in sampling is itself a strong argument for increasing the size of sampling nets to more nearly optimum dimensions than the 0.5 m and 1.0 m nets now in common use.

Acknowledgement

The author is indebted to Dr. BRIAN J. ROTHCHILD, of this Laboratory, for several helpful suggestions made during the course of preparations of this manuscript, and in particular for pointing out the fact that comparison of catches with nets of different physical properties may be useful in estimating behaviour-dependent variability in catches.

Summary

1. The "dodging" problem is analysed in geometric terms by determining the swimming velocity which an organism must attain in order to escape a net of given radius towed at a known speed.

2. For every set of conditions there exists a minimum escape velocity the value of which can be computed and used as a criterion for the design and evaluation of towed-net sampling gear.

3. Under the assumption that the net is towed at the highest possible speed, it is shown that for nets of too small a radius the ease with which the net may be avoided more than compensates for the fact that small nets can be towed at high speed.

4. Similarly, it is shown that too large a net results in a loss in towing speed which more than makes up for the difficulty an organism might have in avoiding a large net.

5. Accordingly, there exists an intermediate, optimum net size such that the minimum escape velocity is as large as possible.

6. For nets of optimum and near-optimum size, catch selectivity should be primarily a function of swimming speed; for non-optimum net sizes the direction in which an organism swims may be as important a factor as swimming speed.

7. The analysis suggests that the greatest penalty is incurred when a net is made much smaller than optimum size, rather than much larger.

8. Marked increases in effectiveness can be expected from new types of nets which are difficult to detect, so that the distance at which organisms begin to react to their approach is minimized.

APPENDIX

Mathematical Analysis

Figure 1 shows the geometry of the problem and the coordinate system and notation used. The coordinate system is a cylindrical one, fixed with respect to the water. The X -axis coincides with the axis of movement of the net. The origin is fixed at the location of the centre of the net opening at the instant when the organism begins to react to the net's approach, at time t_0 . At time t_0 the organism is located at a distance x_0 ahead of the net and a distance r_0 from the X -axis. At a later time, t' , the net overtakes the organism so that both the net opening and the organism are at a distance x' from the origin; at this same time, the organism is located at a distance r' from the X -axis. If capture is to occur, it is evident that r' must be less than R , the radius of the net's opening. In the time interval between t_0 and t' , the net moves along the X -axis with an average velocity of U , while the organism moves with an average velocity of u at an angle θ measured counterclockwise from the direction of the X -axis. We are thus not concerned with the details of the movement of the organism, but only with the initial and final conditions.

In the time interval $t' - t_0$, the net moves a distance x_0 plus the distance travelled by the organism in the X -direction during this same period of time, given by $u \cos \theta(t' - t_0)$:

$$U(t' - t_0) = x_0 + u \cos \theta(t' - t_0) \quad (1)$$

At the same time, the organism has moved through a distance $u \sin \theta(t' - t_0)$ perpendicular to the X -axis, so that its final distance r' is given by:

$$r' = r_0 + u \sin \theta(t' - t_0) \quad (2)$$

which, for capture to occur, must be less than the radius of the net R . Rearranging equation (1) and dividing it into (2) yields:

$$\frac{R}{x_0} > \frac{r'}{x_0} = \frac{r_0 + u \sin \theta(t' - t_0)}{(U - u \cos \theta)(t' - t_0)} \quad (3)$$

where the inequality sign indicates the condition for capture. If we replace R in (3) by $R_{\min}$, and u by $u_{\max}$ to represent the maximum speed with which an organism can move and still be just within the rim of the net opening when overtaken, we obtain the following expression for the minimum radius of a net which will always enclose an organism moving with a speed $u_{\max}$ at an average angle θ , from a start at position (x_0, r_0) , and having a time interval $(t' - t_0)$ in which to react to the net's approach at a speed U along the X -axis:

$$R_{\min} = r_0 + x_0 \frac{(u_{\max} \sin \theta)}{(U - u_{\max} \cos \theta)} \quad (4)$$

For a discussion of the effectiveness of a net, it is instructive to solve equation (4) for $u_{\max}$, which we may re-name the escape velocity, u_e , if we assume that this escape velocity is infinitesimally greater than the maximum velocity for capture $u_{\max}$, as defined above. Equation (4) then becomes:

$$u_e = \frac{U}{\left(\frac{x_0}{R - r_0}\right) \sin \theta + \cos \theta} \quad (5)$$

Equation (5) gives the escape velocity for an organism as a function of the parameters of the problem. Equation (5) is the equation for a straight line which represents the locus of all values of u_e corresponding to one set of values for R , U , x_0 , and r_0 .

In each case there exists a minimum value of u_e , which will be referred to as u_e^* , the minimum escape velocity. This value is illustrated in Figure 2; it corresponds to the perpendicular from point $p(x_0, r_0)$ to the line of equation (5).

It should be remembered that equation (5) only yields one branch of the locus u_e , namely that portion between the X -axis intercept and the value of θ where $\theta = \Phi$ (see Figure 2). The X -axis is an axis of symmetry, and those portions of the locus of u_e which lie on the side of the X -axis opposite of that where point p is found are solutions without physical meaning, although they are mathematically correct. In Figure 2B these invalid solutions for u_e are shown as broken lines. The branches of the curves shown in Figure 2 which lie below the X -axis were obtained from considerations of symmetry about the X -axis.

To determine u_e^* , equation (5) is converted to the general form of a linear equation in Cartesian coordinates, $Ax + By + C = 0$, and thence by dividing by $\sqrt{A^2 + B^2}$, to the normal form, $x \cos \theta + y \sin \theta - p = 0$, where p is the perpendicular distance from the origin to the line u_e and θ has the value of θ^* (see, for example, ESHBACH (1952), p. 2-80, or any other handbook's section on analytic geometry). This procedure yields the equations

$$(R - r_0)x + x_0y - U(R - r_0) = 0$$

and

$$\frac{x + \frac{x_0}{R - r_0}y + U}{\sqrt{1 + \frac{x_0^2}{(R - r_0)^2}}} = 0 \quad (6)$$

where the X - and Y -axes are centred on the position of the organism at time t_0 , replacing the polar coordinate system used previously. The term with U in equation (6) is the desired value of the vector u_e^* :

$$u_e^* = \frac{U}{\sqrt{1 + \frac{x_0^2}{(R - r_0)^2}}} \quad (7)$$

while the angle θ^* is given by

$$\cos \theta^* = \frac{1}{\sqrt{1 + \frac{x_0^2}{(R - r_0)^2}}} \quad (8)$$

To design an effective net, it is necessary to determine the way in which u_e^* varies with changes in R , the radius of the net. We shall, therefore, consider the way in which U varies with changes in R , since U and R are the only variables in equation (7) which are assumed to vary with changes in R . Up to now the discussion has been completely general, applicable to all nets having a circular opening, or to nets which are not circular, in which case R is merely one-half the minimum diameter of the opening. It will be necessary, however, to introduce some assumptions to carry the analysis further. These assumptions are:

1. That the net is towed at the maximum possible speed, so that the major effect of increasing the net's radius is to increase the drag of the net, thus slowing the towing vessel down, and

2. That the drag of the net is proportional to the area presented by the net opening, and to the square of the velocity of tow.

The second assumption is based on the results of theoretical and experimental work on the drag of a body submerged in a moving fluid. Although it would be most desirable to study the details of fluid flow and drag for various towed-net designs, there is little reason to doubt the validity of the second assumption for present purposes. The assumptions lead to the following equation for U as a function of R :

$$U = S - aR^2U^2 \quad (9)$$

where S is the speed of the ship with her engines set for towing, but without encumbrances, R is the radius of the net towed, U is the speed of tow with a given net, and a is an empirical constant combining the dimensions and numerical values of drag coefficients, the power exerted by the vessel, and other similar variables which are independent of R . It is possible to determine a for a given net by running the vessel over a measured distance to determine S ,

then setting the net and determining U , the speed of tow, over the measured course. The value of a is then given by:

$$a = \frac{S - U}{R^2 U^2} \quad (10)$$

which is readily derived from equation (9). With units of centimetres and seconds, it will be found that for most vessels a is of the order of magnitude of 10^{-8} sec/cm³, with larger values for less powerful vessels or nets with inherently higher drag and vice versa. Figure 3 shows curves of towing velocity as a function of net radius, for three values of a , computed from equation (9) in the following form:

$$U = \frac{-1 \pm \sqrt{1 + 4aSR^2}}{2aR^2} \quad (11)$$

remembering that only positive values of U have physical meaning in the present context.

The above approach is of course valid not only for the case where the ship's main engines furnish the motive power, but also in cases where a winch, or a combination of winch and main engines furnish the power.

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**BODY TEMPERATURE OF
YELLOWFIN AND SKIPJACK TUNAS
IN RELATION TO SEA SURFACE
TEMPERATURE**

By
IZADORE BARRETT
and
FRANK J. HESTER



Body Temperature of Yellowfin and Skipjack Tunas in Relation to Sea Surface Temperature

TUNAS are frequently cited as the exception to the generality that fishes are poikilothermic. These references to temperatures higher in tunas than in their environment are mainly based on measurements made with mercury thermometers on isolated specimens at one or two sea temperatures¹, circumstances which result in less-than-accurate temperature measurements, and which fail to describe adequately the body temperature-sea temperature relation over the thermal range of the tunas. The single report² of tuna body temperatures over a wide range of sea temperatures is based on measurements made with the mercury thermometer.

In the course of other investigations, we had the opportunity of measuring, with thermoelectric techniques, the deep-muscle temperatures of 62 live yellowfin tuna (*Thunnus albacares*) (length-range, 530-882 mm) and 31 live skipjack tuna (*Katsuwonus pelamis*) (length-range, 467-555 mm) captured in the eastern tropical Pacific Ocean, at sea temperatures of 19.4°-30.6° C. Body temperatures were measured with either the YSI model 47 telethermometer or the Electrotemp remote reading thermometer, both calibrated against standard mercury thermometers. The thermistor probes were inserted deeply into the lateral muscles, midway between the origins of the dorsal and pectoral fins. Most readings were taken on live fish within 1 min after being brought on deck, after capture by live bait methods³, by purse-seine, or by trolling; the remainder were made on hooked yellowfin swimming in the sea at the end of a line.

The plot of these results (Fig. 1) shows the linear least squares regression of body temperature of each species on the temperature of the environment at the time of capture. The equations are:

$$\begin{aligned} \text{yellowfin body temperature } ^\circ\text{C} &= 0.81 \text{ water temperature } ^\circ\text{C} + 7.47 \\ \text{and skipjack body temperature } ^\circ\text{C} &= 0.58 \text{ water temperature } ^\circ\text{C} + 16.39 \end{aligned}$$

The regression lines are significantly different in both slope and level. The correlation coefficients are 0.95 and 0.87 for the yellowfin and skipjack, respectively.

Over the size range of the fish tested, length was of minor importance in the body temperature-sea temperature relation for the yellowfin (body temperature $^\circ\text{C} = 6.49 + 0.86 \text{ water temperature } ^\circ\text{C} - 0.0002 \text{ body length mm}$, for the 53 fish for which length measurements were available). In the skipjack, however, the small fish tended to

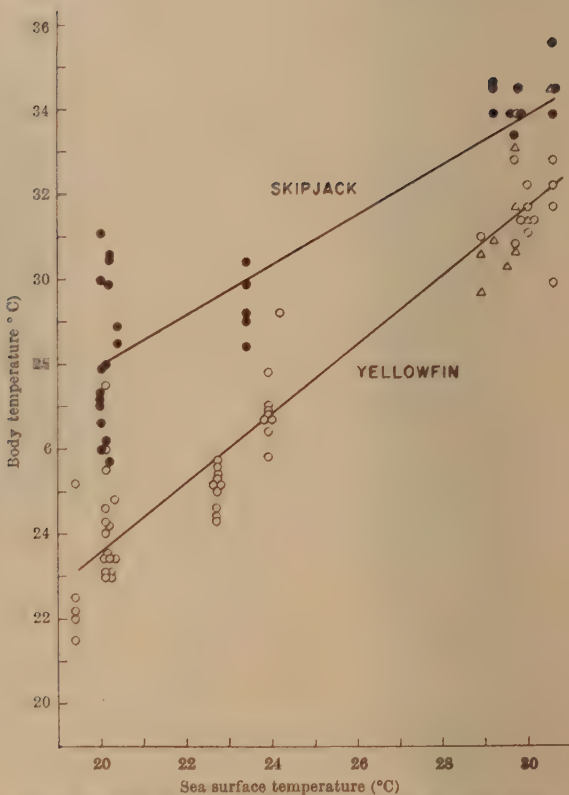


Fig. 1. Relation of body temperature to sea surface temperature.
 ●, Skipjack; ○, yellowfin; △, yellowfin in sea

have lower body temperatures than did the large (body temperature $^{\circ}\text{C} = 8.63 + 0.59$ water temperature $^{\circ}\text{C} + 0.015$ body length mm).

Although the effects of stimulation, handling, heat gradients within the fish, and fish size must be considered in assessing these results, the similarity of the temperatures of yellowfin in the sea (Fig. 1, triangles) to those of yellowfin on deck immediately after capture (Fig. 1, open circles) suggests that the line for the yellowfin is valid. No such confirmatory results are available for the skipjack, but there is little reason for suspecting the validity of the line.

Examination of blood haemoglobin-levels⁴, muscle glycogen content⁵, blood lactate accumulation⁶, and mortalities after handling⁶ and tagging⁷ in both the yellow-

fin and skipjack indicates that these two species live at a higher physiological rate than do other fishes which have been examined, the skipjack more so than the yellowfin⁶⁻⁷. The temperature results given here offer confirmatory evidence of this.

We thank the masters and crews of the motor vessels *San Juan*, *Julia B.* and *Red Rooster* for their help in this investigation. Mr. Ami Dolev, University of California at Berkeley, helped with the measurements aboard the M.V. *San Juan*. One of us (I. B.) was supported in part by funds from contract 14-17 001-844 between the U.S. Bureau of Commercial Fisheries and the Institute of Marine Resources, University of California.

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EYE LENS WEIGHT AND AGE IN THE FUR SEAL

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EYE LENS WEIGHT AND AGE IN THE FUR SEAL

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Abstract: From the weight of the dried eye lenses of 146 fur seals (*Callorhinus ursinus*), the relationship between lens weight and age is tabulated and discussed. Lens weight increased geometrically in both sexes and was still increasing in the oldest specimens studied: a 14-year male and a 21-year female. When only the lens weight and sex are known, the age of a seal can be identified to the nearest year through age 2.

In 1958, the lenses of 12 seals of known age and of 23 seals of estimated age were collected on the Pribilof Islands, Alaska, and sent to the Illinois Natural History Survey, where Rexford D. Lord, Jr., and Glen C. Sanderson made a preliminary study of the relationship between lens weight and age. The findings (unpublished) prompted the collection of a new series of lenses in 1962, all of them from tagged, known-age seals. Only the data from the 1962 series are discussed below. In the series were (1) lenses from 8 pups tagged at birth on the Pribilof Islands on June 28 and 29, 1962, and recovered at ages of 72–120 days, and (2) lenses from 138 seals older than pups, tagged on the islands at estimated ages of 1–4 months and recovered in later years either on the islands or in waters off the Pacific Coast of the United States. For these older seals, the age in years, at death, was known and the age in months was estimated on the basis of a postulated birthdate of mid-July. Repeated observations have established that most Pribilof fur seals are born in July. We thank Dr. D. G. Chapman, University of Washington, for statistical assistance.

METHODS

The lenses were preserved, dried, and weighed according to the method used by Lord (1959) in his pioneer study of lens

weight in the cottontail rabbit (*Sylvilagus floridanus*).

Both lenses of each fur seal were collected and were labeled separately. They were dried in an embedding oven at 78°C for 36 hours. Upon removal, they were placed for a few minutes in a desiccator to cool. The preliminary study by Lord showed that weights need only be taken to the nearest centigram. A triple-beam bal-

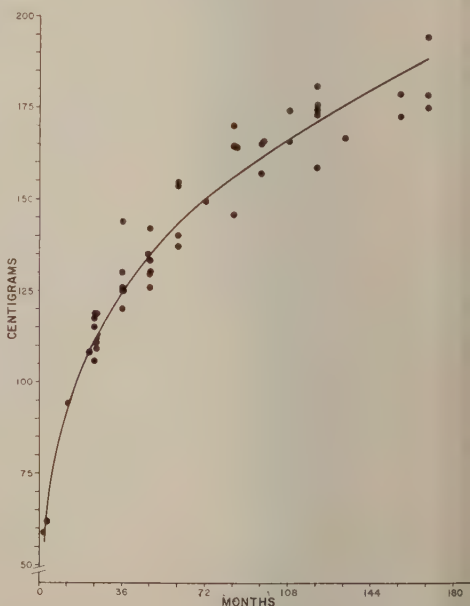


Fig. 1. Increase in lens weight (centigrams) with age (months). Each point represents the mean weight of right and left lenses of one seal. Males, $N = 49$.

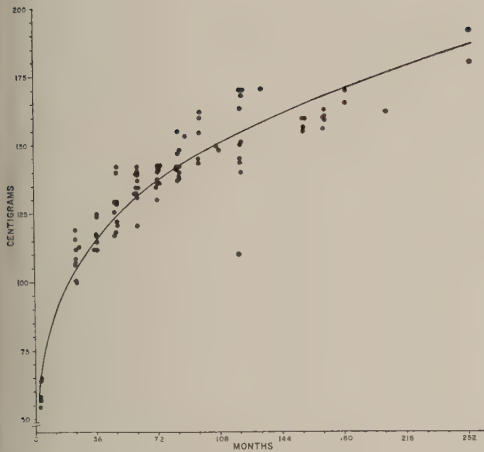


Fig. 2. Increase in lens weight (centigrams) with age of seal (months). Females, $N = 97$.

ance recording to the nearest centigram was used in our study.

RESULTS

A curvilinear relationship between age and lens weight was found (Figs. 1 and 2). Several means of transforming the data were used to determine the type of equation which would best describe the relationship and make the data linear, with homogeneous variance. A logarithmic transformation yielding an equation of the type $Y = ax^b$ gave the best results. This type of equation, or a modification of it, was used by Dudzinski and Mykytowycz (1961), Kolenosky and Miller (1962), and Kingsmill (1962) to describe the relationship between age and lens weight in the wild rabbit (*Oryctolagus cuniculus*), pronghorn antelope (*Antilocapra americana*), and brush-tailed opossum (*Trichosurus vulpecula*).

The equations describing the relationship of lens weight and age in our study are $Y_m = 47.11X_m^{0.2698}$ and $Y_f = 48.20X_f^{0.2446}$ for males and females, respectively,

Table 1. Comparative weights of right and left lenses in 99 seals.

SEX	NUMBER OF SEALS	NUMBER HAVING		
		Right Lens Heavier	Left Lens Heavier	Lenses Equal
Male	40	22(53%)	13(35%)	5(12%)
Female	59	24(41%)	27(46%)	8(13%)
Total	99	46(47%)	40(40%)	13(13%)

where X is age in months and Y is lens weight in centigrams.

Analysis of covariance showed that there was no significant difference in the rate of lens growth between the sexes; however, the lens weight for males was significantly heavier ($P < 0.01$).

The lenses from 99 seals were labeled individually as either right or left. On the basis of these, we compared the weights of the right and left lenses (Table 1).

The value of lens weight as an indicator of age can be measured by determining the variation in the ages for a given lens weight. This was done by reversing the roles of the variables, age and lens weight, thus making lens weight the independent variable—the only means of placing confidence limits on age estimated from lens weight. Table 2 shows these 95 percent confidence limits for some ages. The equations for estimating age from lens weight are

$$\log Y_m = 3.66690 \log X_m - 14.09903$$

and

$$\log Y_f = 3.805006 \log X_f - 14.45143$$

for males and females, respectively, where Y is now the age in months, the dependent variable, and X is lens weight in centigrams.

DISCUSSION

Of interest is the finding that lens weight increases in the male and in the female to at least the ages of 14 and 21

Table 2. The 95 percent confidence limits for some ages, estimated from the regression of age on lens weight.

AGE		CONFIDENCE LIMITS (MONTHS)	
Months	Years	Males	Females
2		1-3	1-3.5
12	1	8-18	7-20
24	2	16-36	14-40
36	3	24-54	21-61
48	4	32-72	29-81
60	5	40-90	36-101
72	6	48-109	43-121
84	7	55-128	50-141
96	8	63-147	57-162
108	9	70-167	64-182
120	10	77-186	71-202
144	12	91-227	86-243
168	14	105-269	100-283
192	16	118-312	114-323
216	18	131-355	128-364
240	20	144-400	142-405

years, respectively. We conclude that it increases throughout life, for the maximum life-span is probably not much longer than 26 years. (From unpublished data of our laboratory: 2,387 female seals more than 10 years old were collected in waters off the Pacific Coast of the United States from 1958 to 1961. Of these, only 29 (1.2 percent) were over 20 years old. Only one seal as old as 26 years was collected.)

Increase in weight of the lens is evidently governed by factors unlike, or carrying beyond, those which govern increase in body weight. Scheffer and Wilke

(1953:134) showed that body weight in the seal increases little, if at all, after the age of 10 years.

Except in 1- and 2-year-olds, variation in lens weight within an age-class is greater than yearly growth. Overlapping of lens weights above age 2 indicates that lens weight can have little application as a criterion of age. Thus, a male estimated from lens weight to be 84 months old could be anywhere from 55 to 128 months, and a female estimated to be 84 months could be from 50 to 141 months (Table 2).

From the weights of 99 pairs of lenses, we conclude that neither the right nor the left lens tends to be heavier.

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AGE OF NORTHERN FUR SEAL AT COMPLETION OF ITS FIRST MOLT

By study of the pelage of young northern fur seals (*Callorhinus ursinus*) an estimate has been made of the mean age when the seals complete their first molt. From a series of newborn pups marked on 28 and 29 June 1962, on St. Paul Island, Alaska, Bauer and Peterson subsequently recovered, between 9 September and 19 October, 6 pups of known ages 73 to 103 days. They preserved in formalin a small sample of skin from the mid-back of each pup. Scheffer made transverse sections of the samples and identified the stages of molt (Table 1).

TABLE 1.—Features of the first molt of the fur seal with relation to age

Features of the molt	AGE OF PUP IN DAYS					
	73	73	82	83	92	103
Molt stage	mid	late	post	ending	late	ending
Color phase ¹	black	black	silver	silver	black	silver
Fetal overhairs persistent; pigment forming in new underfur and guard hair bulbs	yes	yes	no	no	yes	no
Specimen data						
Sex	F	M	F	F	F	M
Date	9 Sept.	9 Sept.	19 Oct.	19 Sept.	28 Sept.	9 Oct.
Length, cm	73	72	81	73	66	80
Weight, kg	8.5	7.4	11.2	8.0	8.4	11.6

¹ General color effect of dorsal pelage. By convention, the first-summer young is called initially a "black pup" and later a "silver pup."

The first pelage of the seal is jet black over most of the body (Scheffer, Victor B. *North American Fauna* No. 64, pp. 61-62, 1962). It is well established in fetal life in April when the fetus has normally attained a weight of about 2.5 kg, or about half of its ultimate weight at birth. The black pelage is mature and functional at time of birth. It is relatively simple in structure and it consists of skin-pore units, each with a coarse overhair and one or 2 fine underhairs.

The second pelage is silvery gray and is essentially like that of the adult. It consists of skin-pore units, each with a coarse guard hair and 14 to 24 underfur fibers. From repeated observations in 1962 and earlier, it is known that nearly all pups change in color from black to silvery gray between mid-September and mid-October. From the new evidence of the 6 known-age specimens, it is concluded that molt can be completed in pups as early as 11 weeks after birth and as late as 15 weeks, with a mean of about 13 weeks.

On the basis of 7 July 1962 as the mean date of birth, estimated by Peterson from observations of 797 births, and 13 weeks as the mean age of the pup at completion of its first molt, the mean completion date would be 7 October.—RICHARD D. BAUER, RICHARD S. PETERSON AND VICTOR B. SCHEFFER, *Marine Mammal Biological Laboratory, Bureau of Commercial Fisheries, U. S. Fish and Wildlife Service, Seattle 15, Washington. Received 16 February 1963.*

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Aspects of the Development of the Upper Jaw Bones in Teleosts

FREDERICK H. BERRY

Aspects of the Development of the Upper Jaw Bones in Teleosts

FREDERICK H. BERRY

The ossification and subsequent morphological development of the upper jaw bones were studied in ontogenetic series of selected species of five orders of bony fishes: Isospondyli, Iniomi, Anacanthini, Percomorphi, and Pediculati. In the Isospondyli, the maxillaries are the first bones to develop in the upper jaw; the premaxillaries develop next and remain in the anterior part of the jaw with the maxillaries occupying most of the gape; in a few exceptions the premaxillaries continue to grow posteriad during juvenile and adult stages. In most species of the Iniomi and the other more advanced orders, development of the jaw bones is initially similar to that in the Isospondyli, but subsequently, during the larval stage, the premaxillaries continue to grow posteriad under the maxillaries and force the maxillaries completely or largely out of the gape.

THE 2 major bilaterally paired bones in the upper jaw of teleosts are the maxillaries and the premaxillaries. The positional relations of these bones have been used in defining the higher classification of certain teleosts. This character is one of the most trenchant in separating the orders Isospondyli and Iniomi. In the Isospondyli "the maxillary enters in the gape." In the Iniomi "the maxillary is excluded from the gape." Many species of the order Ostariophysi are similar in this to the Isospondyli; the remainder of the Ostariophysi and the great majority of species in the other orders of bony fishes are similar to the Iniomi. This paper describes aspects of the development of these 2 pairs of bones and their positional relations in several orders of bony fishes, with emphasis on the Isospondyli and Iniomi, and discusses certain exceptions to previous characterizations of these 2 orders.

I am grateful to Leonard P. Schultz and George S. Myers for making specimens

available for examination and to Elbert H. Ahlstrom, William A. Gosline, David Kramer, John S. MacGregor, Giles W. Mead, and Charles P. O'Connell for reviewing the manuscript.

METHODS

Larval fishes used in this study are from the plankton collections of the Bureau of Commercial Fisheries Biological Laboratory at La Jolla, California. Juvenile and adult fishes were examined at a number of institutions, primarily the U. S. National Museum.

All larvae and many of the later stages were prepared by clearing with potassium hydroxide and staining with alizarin in a technique modified from Clothier (1950). All illustrations were made from this cleared and stained material, and several are diagrammatic to emphasize pertinent structures and to characterize ordinal or familial groups more broadly. The 4 kinds of upper jaw bones are distinguished in the



Fig. 1. Diagrammatic illustration of the three principal series of bones in the upper jaw of Isospondyli. Premaxillaries—cross-hatched, maxillaries—stippled, supramaxillaries—clear.



Fig. 2. Diagrammatic illustration of the upper jaw bones in certain genera of the isospondylus family Clupeidae that possess the bilaterally paired hypomaxillary (diagonal lines).

illustrations as follows: premaxillaries—cross-hatched, maxillaries—stippled, supramaxillaries—clear, and hypomaxillaries—diagonal lines slanting downward to the left. Median rostral processes are depicted by diagonal lines slanting downward to the right.

DEFINITIONS

Premaxillaries.—Bilaterally paired bones at the anterior end of the upper jaw. The premaxillaries may join at the symphysis, may overlap and may be fused, or they may be relatively widely separated. They may bear teeth, may be toothless, or may be excluded from the biting surface of the jaw. In some species the premaxillaries have been described as missing. In older literature, they have been termed intermaxillary, surmaxillary, or bimaxillary.

Maxillaries.—Bilaterally paired bones usually comprising the major part of the upper jaw and usually located posterodorsally to the premaxillaries. The maxillaries usually are separated from each other at their anterior ends. They usually articulate with the premaxillaries anteriorly, or may be held closely to the premaxillaries by connective tissue, or may be fused to the premaxillaries. The maxillaries are generally toothless, but in certain fish groups they comprise the major toothed and biting surface of the upper jaw.

Supramaxillaries.—Bilaterally paired bones located along the posterodorsal portion of the maxillaries. In various fish groups, the

supramaxillaries may be absent or 1 or 2 pairs may be present. When 2 pairs are present, 1 posterior pair usually is larger, and may form the expanded posterodorsal surface of the jaw. The supramaxillaries are toothless, and may be fused to each other and/or the maxillaries. The anterior pair of supramaxillaries may be designated as #1, the larger and posterior pair of supramaxillaries as #2 (when 1 of these is missing in a species, it appears to be #1).

Hypomaxillaries.—Bilateral pairs of bones located in the gape between the posterior end of the premaxillaries and ventral flexure of the maxillaries in certain diverse genera of the isospondylous family Clupeidae. The hypomaxillaries are unattached, although their posterior ends may lie over a portion of each maxillary. They usually are toothed (Berry, In press).

Gape.—The opening of the mouth or the expanse of the open mouth. Some interpretations of the positional relation of the upper jaw bones obviously have been made from preserved specimens in which the mouth was closed. A more meaningful interpretation is possible when the relative positions are examined with the jaws fully opened. In this perspective many fishes in the higher orders do have the posteroventral curve of the maxillaries included in the gape, so that the maxillaries cannot be described as precisely being excluded from the gape; but in most of these they are essen-

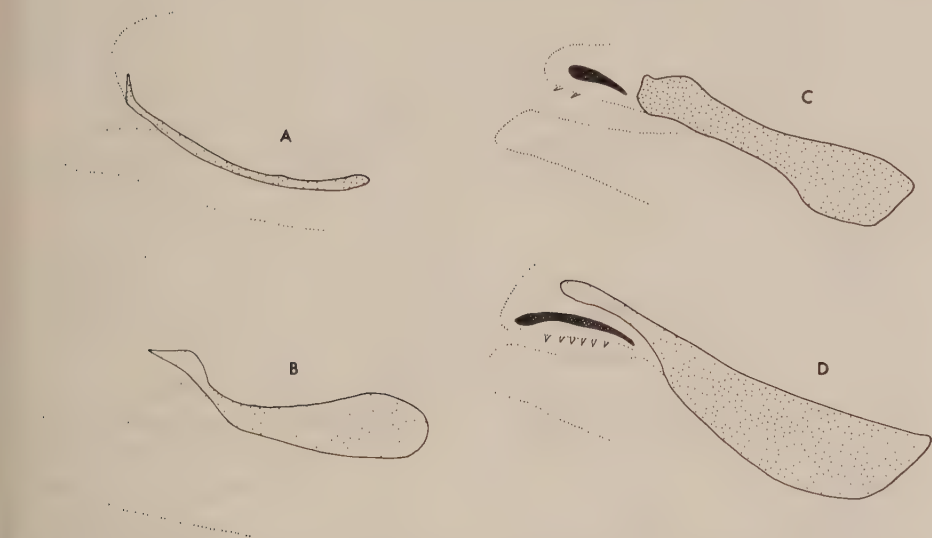


Fig. 3. Development of the upper jaw bones in the isospondylus bathylagid genus *Leuroglossus*. A, 7 mm SL; B, 10.5 mm; C, 20 mm; D, 62 mm.

tially excluded from the functional biting surface of the upper jaw.

Formation and development.—This has not been a study of formation of the elements of the upper jaw, because the bones are preformed in unossified connective tissue. The alizarin staining techniques emphasize only bone that has become calcified, and the statements and conclusions in this paper are a reflection of this condition of development through ossification.

ISOSPONDYLI (CLUPEIFORMES)

In the Isospondyli, the premaxillaries usually are confined to the anterior portion of the upper jaw, and the maxillaries occupy the major portion of the ventral margin of the jaw (Fig. 1). In certain genera (*Harengula*, *Pliosteostoma*, *Pellona*), a bilateral pair of hypomaxillaries may be present (Fig. 2).

Development of the upper jaw bones was studied in the following isospondylids: *Sardinops* (Clupeidae), *Engraulis* (Engraulidae), and *Leuroglossus* (Bathylagidae). The development in all 3 is very similar to that described for *Leuroglossus* (however, the bathylagids are atypical isospondylids in that the premaxillaries do not enter into the effective biting surface).

In *Leuroglossus*, the first bones to develop in the upper jaw are the maxillaries, ossifying at about 7 mm standard length (SL) as narrow rods along most of the biting surface (Fig. 3A). At 10.5 mm, the maxillaries have recessed anteriorly and expanded posteriorly (Fig. 3B). By 20 mm, the small premaxillaries have formed (Fig. 3C). By the 62-mm size depicted in Fig. 3D, the maxillaries and premaxillaries have completed their development. The premaxillaries and maxillaries are toothless at all stages, and teeth shown in Figs. 3C and 3D are on the vomer and palatine.

Some genera of Isospondyli have been described erroneously as having the maxillaries withdrawn from the upper border of the mouth: *Albula* (Albulidae), *Pterothrissus* (Pterothrissidae), *Nematalosa* (Clupeidae), *Chanos* (Chanidae), *Aplochiton* and *Prototroctes* (Aplochitonidae) (Bigelow, 1964:92). Ridewood (1904:49–50) described the situation in *Albula* as: "Unless the mouth is very widely opened, the premaxilla alone bounds the gape above." Examination of the above genera shows them to be atypical isospondylids in that the premaxillaries extend farther posteriorly and occupy more of the border of the jaw than in other isospondylids; but the posteroventral margin of the maxillaries defi-

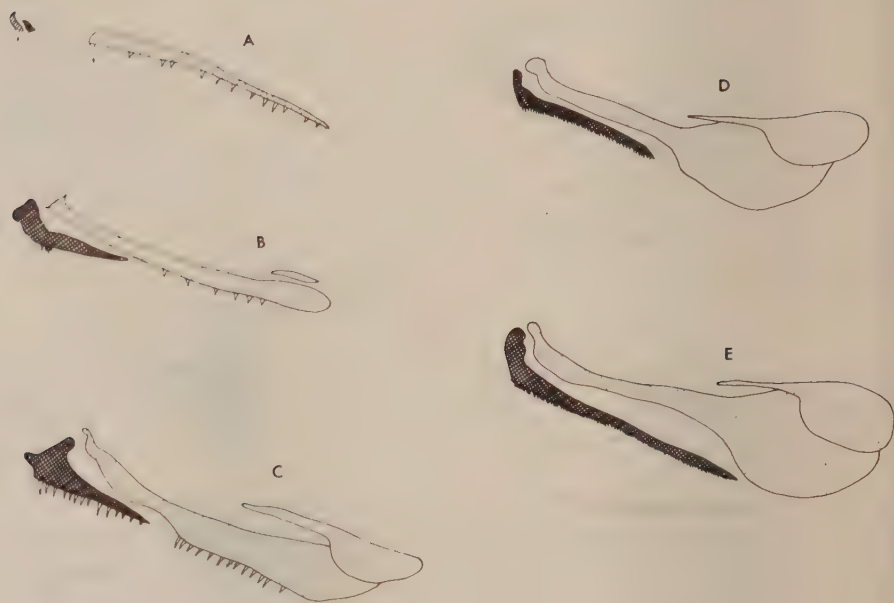


Fig. 4. Development of the upper jaw bones in the isospondylus albulid genus *Albula*. A, 67 mm SL; B, 29 mm; C, 37 mm; D, 120 mm; E, 270 mm. Rostral process—diagonal lines.

nitely enters into the gape in forming the posterior margin of the upper jaw. Some of the other aberrant genera may be similar to *Albula* (described below) in which this condition is produced by a protracted posterior growth of the premaxillaries that continues through the juvenile into the adult stage, and possibly throughout life.

The development of the upper jaw bones in *Albula*: In a 67-mm SL leptocephalus stage (Fig. 4A), the maxillaries are toothed and occupy about the posterior three-fourths of the border of the upper jaw; the other upper jaw elements of this stage have not been studied critically, but the tooth-bearing median and unpaired element at the tip of the jaw appears to be a transitional rostral process, and the 2 small bilateral bones just posterior to this represent the premaxillaries. In a 29-mm metamorphosed juvenile (Fig. 4B) the median rostral process has disappeared, the premaxillaries bear a few teeth and have grown posteriorly under the anterior margins of the maxillaries, the maxillary dentition has

been reduced, and the single pair of supra-maxillaries has ossified. At larger sizes, 37 mm (Fig. 4C), 120 mm (Fig. 4D), 270 mm (Fig. 4E), the premaxillaries continue to grow posteriad excluding the major part of the maxillaries from the gape, and the maxillaries become edentulate and form expanded posterior portions.

Premaxillaries are described as absent in certain opisthroproctoids, *Macropinna* (Chapman 1942:279) and *Dolichopteryx*



Fig. 5. Diagrammatic illustration of the upper jaw bones of *Iniomi*.



Fig. 6. Development of the upper jaw bones of the iniomous genus *Scopelosaurus*, lateral view. A, 10 mm SL; B, 18 mm; C, 23 mm; D, 29 mm; E, 46 mm.

and *Bathylychnops* (Cohen 1958:47-48). The premaxillaries may be present in very small larval stages, but they are absent in a *Macropinna microstoma* larva of 14 mm SL. The mesethmoid is expanded laterally in larval *Macropinna* to occupy the space where the premaxillaries occur in larval *Leuroglossus*.

INIOMI (MYCTOPHIFORMES)

In the Iniomi, the premaxillaries occupy the entire ventral border of the upper jaw; the maxillaries are dorsal to the premaxillaries and may be fused to them (Fig. 5). However, this description applies to the late larval, juvenile, and adult stages, and the attainment of this condition during larval development involves some interesting morphogenetic features.

The development of the upper jaw bones in the Iniomi was studied in an undescribed species of *Scopelosaurus* (Scopelosauridae) from the California Current. This was fortuitous, but fortunate, because this species has a relatively protracted larval stage, re-

maining a larva to a size slightly greater than 46 mm SL, thereby protracting the development of the jaw bones. The first bones to ossify in the upper jaw are the curved and toothed maxillaries which occupy the major portion of the ventral border of the jaw; this occurs at about 10 mm SL (Fig. 6A); in the smallest specimen in which the maxillaries were developed, there were 7 small teeth spaced along most of the border of each of the paired bones. The premaxillaries ossify by 18 mm, bear a few teeth, and extend under the anterior margin of the maxillaries (Fig. 6B); and teeth are now excluded from about the anterior third of the maxillaries of this stage. The premaxillaries continue to grow posteriad, and teeth form along their extending ventral surface (23 mm, Fig. 6C; 29 mm, Fig. 6D). The premaxillaries grow backward under the ventral margin of the maxillaries with the result that the maxillaries are progressively pushed out of the ventral border of the jaw and lose their teeth. The maxillaries are toothless by 29 mm (Fig. 6D),

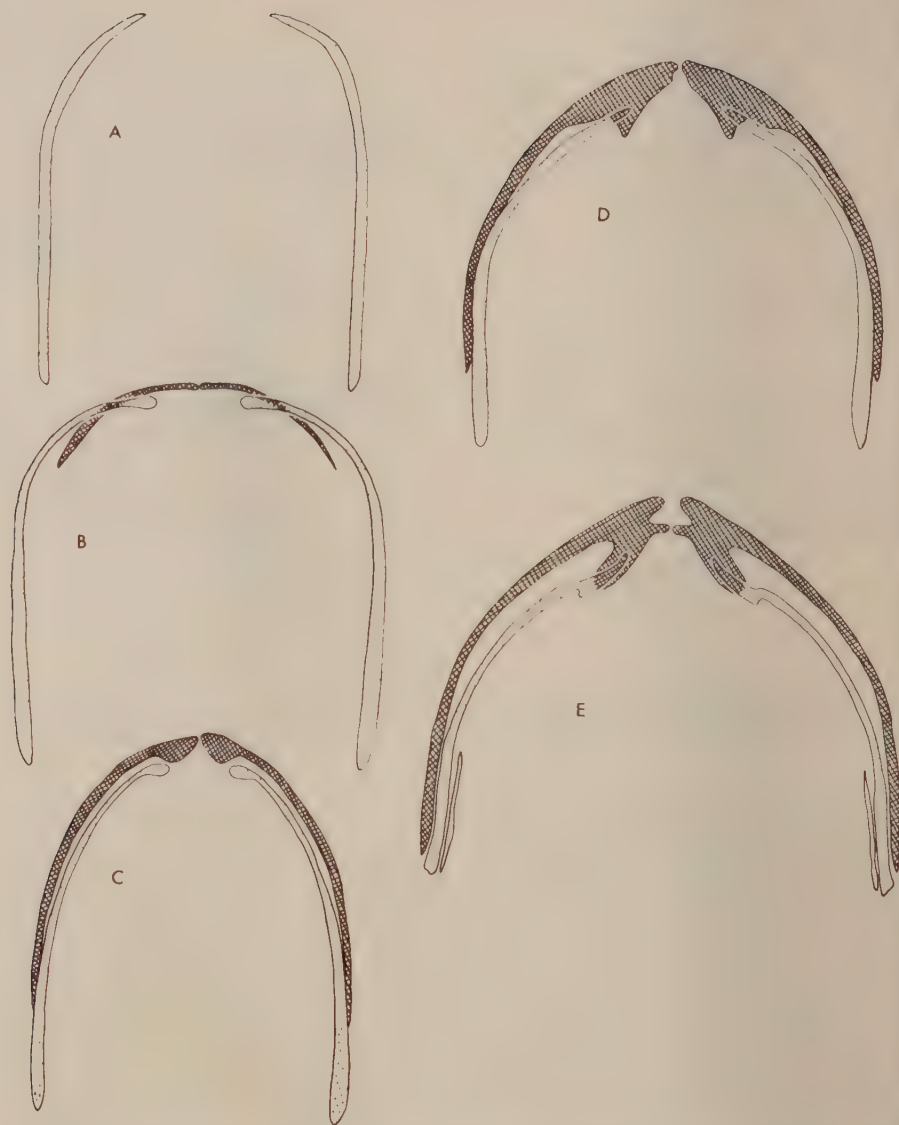


Fig. 7. Dorsal view of development of the upper jaw bones of *Scopelosaurus* as shown in Fig. 6.

and by 46 mm (Fig. 6E) they are entirely excluded from the gape. The single pair of supramaxillaries is formed at about 40 mm. The sequence of development shown in Fig. 6 is presented in dorsal aspect in Fig. 7 to provide a three-dimensional perspective of this process. This shows that the converging anterior ends of the maxillaries remain separated across the median plane,

while the premaxillaries form near the symphysis, and their anterior ends abut at the symphysis.

This developmental process has been examined in 3 other iniomid genera: *Lampasnyctus* (Myctophidae), *Synodus* (Synodontidae), *Benthalbella* (Scopelarchidae). The development of the upper jaw bones of these other Iniomids is similar to that in

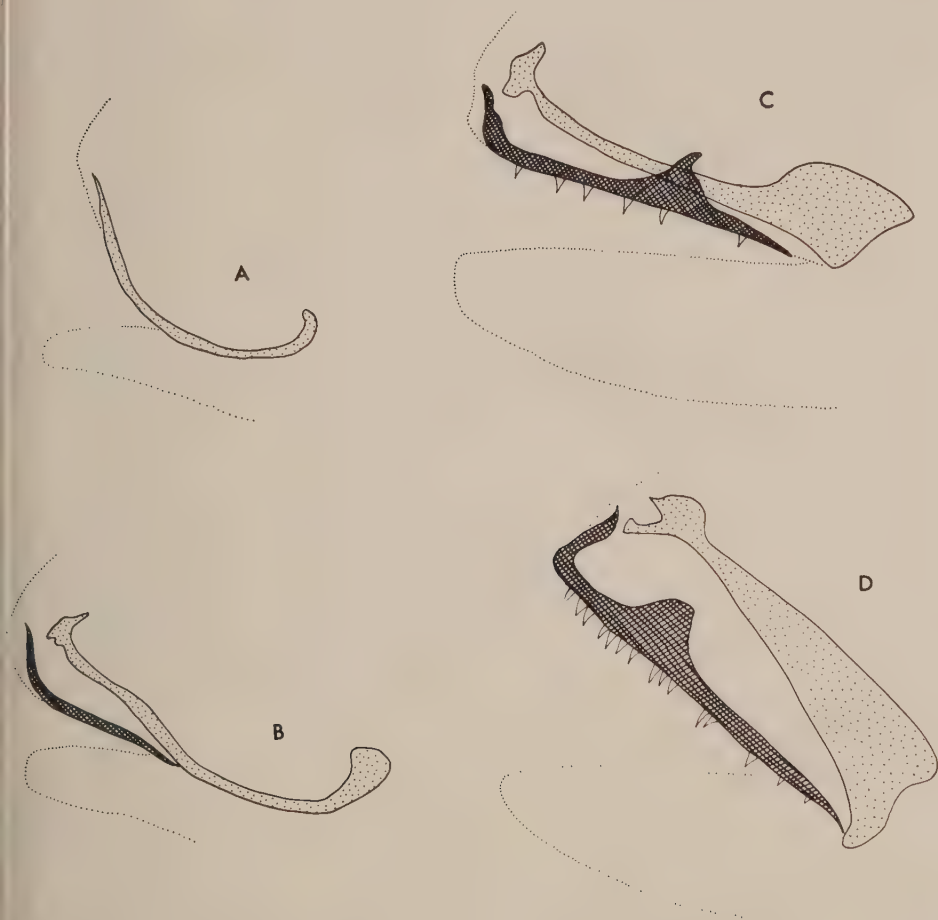


Fig. 8. Development of the upper jaw bones in the gadid genus *Merluccius*. A, 3.4 mm SL; B, 4.6 mm; C, 6.0 mm; D, 15 mm.

Scopelosaurus, except that in none of these do teeth develop on the maxillaries.

Thus, from this limited survey of the 2 orders, it appears that the development of the bones of the upper jaw is essentially the same in the larvae of the *Isoospondyli* and the *Iniomii*. The distinguishing character of these 2 orders is produced by the *iniomii* premaxillaries continuing to grow posteriad, forcing the maxillaries out of the border of the jaw. This situation might be used to support the theory of ontogeny (of the *Iniomii*) recapitulating phylogeny (of the *Isoospondyli*).

GIGANTUROIDEA (GIGANTURIFORMES)

In the two genera of the monotypic order *Giganturoidea*, Walters (1961:313) described

2 pairs of upper jaw bones: the short, expanded, and toothless maxillaries entering about the posterior one-fourth of the gape, and the strongly toothed bilateral bones occupying most of the border of the gape that he termed the autopalatines, concluding that the paired premaxillaries had been lost and had been replaced by these autopalatines. A study of the jaw development in larvae and juveniles of this group will clarify this issue, but such specimens are as yet unknown.

APODES (ANGUILLIFORMES)

In the eels the premaxillaries have been reported by some authors to be "altogether wanting" as by Norman (1951:108); but in a developmental study of *Anguilla vulgaris*,

Norman (1926) had described the presence of the maxillaries in a 5-mm leptocephalus and the appearance of "rudiments" of the premaxillaries in leptocephali of 40 to 78

mm. The existence of the premaxillaries in Apodes and their fusion to each other and their usual fusion to the fused ethmoids and vomer have been clarified by Gosline (1952:131).

ANACANTHINI (GADIFORMES)

Upper jaw development was examined in one genus, *Merluccius* (Gadidae). The development is very similar to that of the Iniomi. The maxillaries form first at about 3.4 mm along the ventral border of the jaw (Fig. 8A). The premaxillaries form at about 4.6 mm (Fig. 8B), grow posteriad under the maxillaries to push the maxillaries out of the gape, and become toothed (6.0 mm, Fig. 8C; 15 mm, Fig. 8D).

PERCOMORPHI (PERCIFORMES)

The upper jaw development was examined in 1 genus, *Trachurus* (Carangidae). This development was similar to that in the Iniomi and the Anacanthini. The maxillaries ossify first, at about 3.0 mm (Fig. 9A). The premaxillaries form next, become toothed at about 4.5 mm (Fig. 9B), and grow posteriad to essentially exclude the maxillaries from the gape by 18 mm (Fig. 9C).

PEDICULATI (LOPHIIFORMES)

A very interesting morphogenesis of the upper jaw bones in the suborder Ceratioidea is suggested by combining my observations on very small larvae from the California Current with the description of later larvae and free-living and parasitic males by Bertelsen (1951). This compilation is outlined in Fig. 10.

In this suggested ontogeny, the maxillaries form first and occupy the major portion of the ventral surface of the jaw (Fig. 10A). The small premaxillaries develop anteriorly (Fig. 10B). The premaxillaries grow posteriad under the maxillaries (Fig. 10C) until they exclude the maxillaries from the gape and form teeth (Fig. 10D). The head of the premaxillaries enlarge (Fig. 10E). A median toothed rostral process ossifies at the tip of the jaw, and the posterior ends of the premaxillaries begin to degenerate (Fig. 10F). The rostral process enlarges, the posterior part of the premaxillaries essentially disappears, and the premaxillaries lose most of their teeth (Fig. 10G). The premaxillaries completely disappear and the maxillaries begin to degenerate (Fig. 10H). Thus we have in this pro-

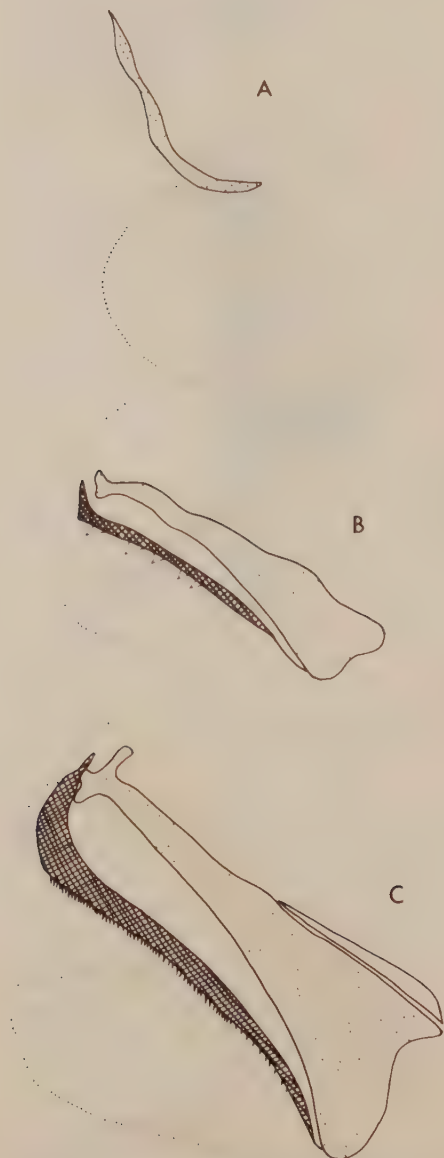


Fig. 9. Development of the upper jaw bones in the percomorph genus *Trachurus*. A, 3.0 mm SL; B, 4.5 mm; C, 18 mm.

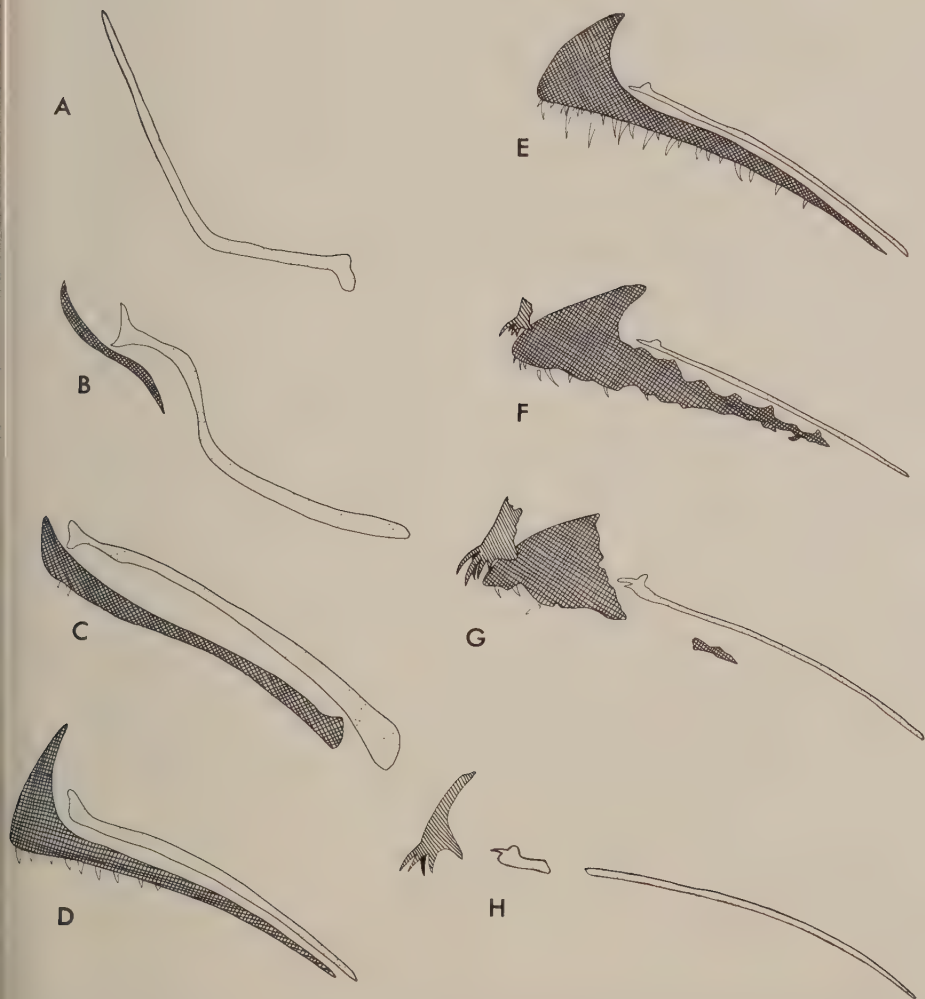


Fig. 10. Development of the upper jaw bones in different stages and species of Ceratioidea. A, larva, probably *Oneiroides*, from California Current, 2.7 mm. B, larva, probably *Oneiroides*, from California Current, 2.4 mm. C, larva, *Neoceratias*, Bertelsen Fig. 105c₂, 8.5 mm. D, free-living male, *Photocorynus*, Bertelsen Fig. 108a₂, 15 mm. E, F, G, H, parasitic males, *Linophryne*, Bertelsen Fig. 5, sizes 19, 22, 20, and 23 mm, respectively.

sumed and very specialized ontogeny almost a complete cycle: from a boneless jaw, to developing maxillaries, to the presence of maxillaries and premaxillaries, to the degeneration and loss of the premaxillaries, to degenerating maxillaries, and potentially again to a boneless jaw.

SUMMARY

In the development of the upper jaw in the *Iso-spondyli*, the paired premaxillaries

develop subsequent to the maxillaries and remain in the anterior portion of the jaw, with the maxillaries occupying most of the lower border of the jaw, except for a few diverse genera in which the premaxillaries continue to grow posteriad during juvenile and adult stages to occupy the major portion of the gape. The generalized isospondylous jaw development is the primitive condition, and the one that apparently prevailed in the more primitive fossil forms

(Gregory 1933, Fig. 283). Development of the upper jaw in the Iniomi is similar initially to that in the Isospondyli, but while still in the larval stage the premaxillaries continue to grow posteriad and force the maxillaries completely out of the gape. The presence of transitory teeth on the maxillaries in larval *Scopelosaurus* may be indicative of a close phylogenetic association of this family with the Isospondyli. Representatives of other, higher orders of fishes studied develop the upper jaw structure in a manner similar to that in the Iniomi. This indicates that fishes in most of the evolutionary lines more advanced than the Isospondyli reflect or pass through the primitive condition of upper jaw structure during their larval period, and differ from this primitive condition only by a continued extension posteriad of the premaxillaries.

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A Hypomaxillary Bone in *Harengula* (Pisces: Clupeidae)

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THE HERRING GENUS *Harengula* Valenciennes (as herein restricted) contains five bilateral pairs of bones in the upper jaw (Fig. 1A). Most other clupeid fishes contain three or four such pairs of bones: premaxillary, maxillary, and one or two supramaxillaries. The extra pair of bones in *Harengula* is here termed the hypomaxillary. The hypomaxillary also occurs in the clupeid genera *Pliosteostoma* Norman and *Pellona* Valenciennes, and its presence has been used to distinguish these two genera from other genera. The presence of the hypomaxillary in *Harengula* and its usefulness as a taxonomic character in separating *Harengula* from other closely related genera previously has been overlooked.

The hypomaxillary previously has been termed "an ossified ligament," "a narrow, toothed bone," and "a bone, bearing teeth lying in the membranous section between the distal end of the premaxillary and the middle of the maxillary." It is desirable to have a specific name for this unique pair of bones, and hypomaxillary is a logical choice. Other similar terms that have restricted meaning or are synonyms of other bones are intermaxillary, inframaxillary, bimaxillary, submaxillary, and surmaxillary.

Four closely related genera are involved in the evaluation of this character: *Harengula*

Valenciennes 1847, *Lile* Jordan and Evermann 1896, *Sardinella* Valenciennes 1847, and one whose designation currently is uncertain, but here is referred to as *Clupalosa* Bleeker 1851. (The distinguishing characteristics are listed below.)

The position of the hypomaxillary in *Harengula* is shown in Figure 1A. Its posterior end overlaps the maxillary laterally. The hypomaxillary, premaxillary, and maxillary all bear a single row of small pointed teeth. The connective tissue in the space between the hypomaxillary may also bear teeth. The hypomaxillary was ossified in the smallest specimen examined (16 mm S.L.). The presence of the hypomaxillary and the characteristic elongation of the posterior supramaxillary (Fig. 2A) in *Harengula* have been verified in the following species:

H. clupeiola (Cuvier 1829), St. Lucia, British West Indies, SU35458, and syntype of *H. latulus* Valenciennes, SU32769

H. humeralis (Cuvier 1829), Jamaica, SU5041

H. pensacolatae Goode and Bean 1880, Sanibel Island, Florida, SU36092, and Santos, Brazil, SU36065 (as *S. majorina* Storey 1938)

H. peruana Fowler and Bean 1924, many specimens from Peru to Costa Rica in several institutions

H. thrissina Jordan and Gilbert 1882, many specimens from Pacific Mexico in several institutions

	HYPOMAXILLARY	SHAPE OF POSTERIOR SUPRAMAXILLARY	BILOBED FOLD ON CLEITHRUM
<i>Harengula</i>	present	elongated, ventral constriction anterior	present
<i>Lile</i>	absent	elongated, ventral constriction anterior	absent
<i>Sardinella</i>	absent	rounded, ventral constriction vertical to dorsal constriction	present
<i>Clupalosa</i>	absent	elongated, ventral constriction anterior	present

¹ U.S. Bureau of Commercial Fisheries, Biological Laboratory, Brunswick, Georgia. Manuscript received August 1, 1963.

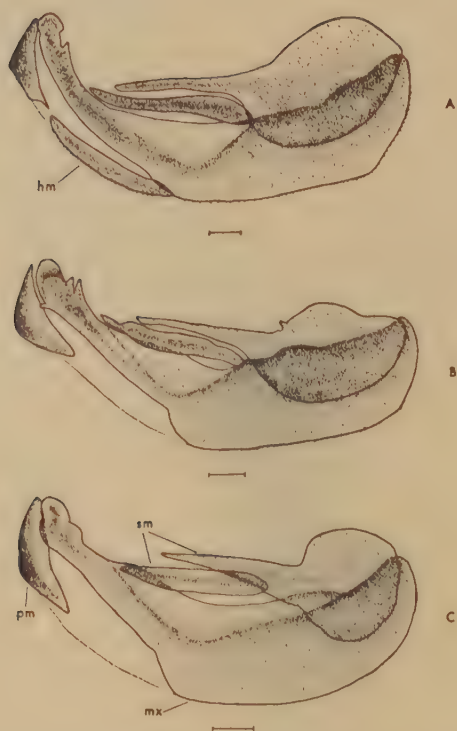


FIG. 1. Upper jaw bones of *Harengula thrissina* (A), *Lile stolifera* (B), and *Sardinella sindensis* (C). Abbrev.: mx, maxillary; pm, premaxillary; sm, supramaxillaries; hm, hypomaxillary. The scale below each is 1 mm.

The presence of the hypomaxillary in the syn-type of *Harengula latulus*, the type species of the genus, is considered to restrict the genus *Harengula* to comparable species possessing this structure. The synonymy of *H. latulus*, the probability of the erroneous original locality designation, and the type species designation were detailed by Storey (1938:36-39), who gave evidence that *Harengula* does not occur in the eastern Atlantic. Based on present information, the genus *Harengula* apparently occurs only in the western Atlantic and the eastern Pacific.

Lile lacks the hypomaxillary bones, and the intervening space along the gape between the premaxillary and the maxillary is occupied by unossified connective tissue (Fig. 1B). The elongated supramaxillary is shown in Figure 2B. These two characters have been verified in

L. stolifera (Jordan and Gilbert 1881) on specimens from many eastern Pacific localities in the collections of several institutions. *Lile* apparently only occurs in American waters.

Sardinella is similar to *Lile* in lacking hypomaxillaries (Fig. 1C). The expanded distal end of the posterior supramaxillary is rounded, with the dorsal constriction about vertical to the ventral constriction (Fig. 2C). This has been verified in the following species:

- S. aurita* Valenciennes 1847, Florinapoli Brazil, SU53863 and SU51662
- S. brachysoma* Bleeker 1852, Tai Ping, China SU25701
- S. cameronensis* Regan 1917, West Africa RGMAC 94987
- S. clupeioides* (Bleeker 1849), Singapor China, SU33838
- S. dayi* Regan 1917, Ceylon, SU22866
- S. eba* (Valenciennes 1847), eastern Atlantic RGMAC 94994
- S. fimbriata* (Valenciennes 1847), Manila Philippines, SU20330
- S. jussieuvi* (Lacépède 1803), Manila, Philippines, SU60478
- S. leiogaster* Valenciennes 1847, Sulu Prov Philippines, SU28571
- S. longiceps* Valenciennes 1847, Madras, India, SU35273
- S. melanura* (Cuvier 1829), Malekula Island New Hebrides, SU25031
- S. perforata* (Cantor 1850), Formosa, SU742
- S. rouxi* (Poll 1953), West Africa, RGMAC 94999
- S. sindensis* (Day 1878), Manila, Philippines SU38369
- S. sirm* (Walbaum 1792), Apia, Samoa, SU8984
- S. zunasi* (Bleeker 1854), Onomichi, Japan SU20140

Sardinella occurs in the Atlantic and Indian oceans and in the western Pacific, but not in the eastern Pacific.

Because the genus *Harengula* is restricted to species possessing hypomaxillaries, certain Indian Pacific species, which have usually been placed in *Harengula*, but which lack this pair of bones are tentatively assigned to the genus *Clupalo*. They have the posterior pair of supramaxillaries

elongated, with the ventral constriction anterior to the dorsal constriction. Species of this genus that I have examined are:

C. dispilonotus (Bleeker 1852), Philippines, SU33545

C. punctata (Rüppell 1835), Philippines, SU20885; Pelew Islands, SU37332; Ceylon, SU22892; South Andaman Islands, SU 37100; Philippines, SU28556

C. schrammi (Bleeker 1849), Philippines, SU33538

C. tawilis Herre 1927, Philippines, SU28559

Bleeker erected the genus *Clupalosa* for his monotypic new species *C. bulan* from the Java Sea in 1849. *Clupalosa* has subsequently been placed in synonymy of both *Harengula* and *Sardinella*. I have not seen this species, and the type specimens, if extant, should be examined to confirm its relationships. I presume that it is distinct from the hypomaxillary-bearing *Harengula*, because no species of *Harengula* (as restricted) have been observed from the Indo-Pacific. I presume that it is distinct from the genus *Sardinella*, because it was not included in a recent and comprehensive review of the Indo-Pacific species of *Sardinella* by Chan (MS). However, Regan (1917), who said he examined Bleeker's types of *bulan*, placed that species in synonymy of *Sardinella perforata* (Cantor 1850). Subsequent authors have listed *bulan* as a distinct species, notably Fowler (1941). If *Clupalosa* proves to be unavailable for this genus, the following generic names might apply: *Paralosa* Bleeker 1868 (type species *Harengula valenciennesi* Bleeker 1868), *Wilkesina* Fowler and Bean 1923 (type species *Harengula fijiense* Fowler and Bean 1923), *Herklotsichtbys* Whitley 1951 for *Herklotsella* Fowler 1933 (type species *Harengula dispilonotus* Bleeker 1852), or *Escualosa* Whitley 1940 (type species *Clupea macrolepis* Steindachner 1879). The status and identity of *Macrura* van Hasselt 1823 is uncertain; it has been proposed for species of this group, but also has been suggested as a synonym of *Hilsa* Regan 1916.

Of the four genera discussed above, I have not examined the following nominal species and am not certain of their generic or specific status:

Harengula callolepis Goode 1880

Sardinella albella (Valenciennes 1847)

Sardinella allecia (Rafinesque 1810)

Sardinella aurovittata (Swainson 1839)

Sardinella caeruleovittata (Richardson 1846)

Sardinella dactylolepis (Whitley 1940)

Sardinella desmaresti (Risso 1826)

Sardinella maderensis (Lowe 1836)

Sardinella nymphaea (Richardson 1848)

Sardinella posterus (Whitley 1931)

Lile piquitinga (Schreiner and Miranda

Ribeiro 1903)

Lile platana Regan 1917

Harengula abbreviata Valenciennes 1847

Harengula blackburni (Whitley 1948)

Clupalosa bulan Bleeker 1849

Harengula dollfusi Chabanaud 1933

Harengula hualiensis Chu and Tsai 1958

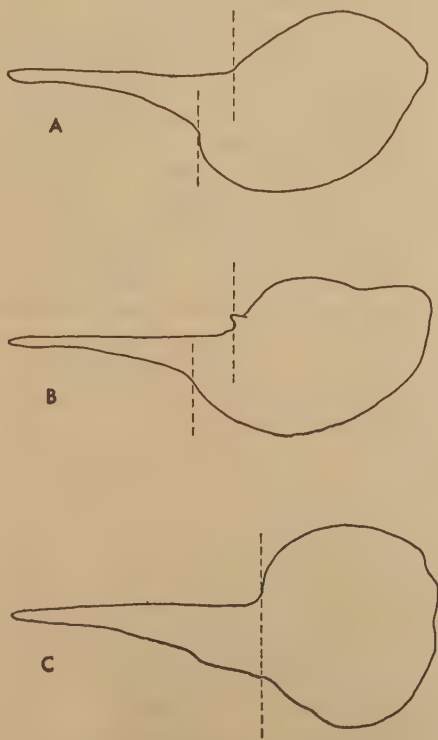


FIG. 2. Posterior supramaxillaries of *Harengula* (A), *Lile* (B), and *Sardinella* (C), showing their characteristic shapes and the relative positions of the dorsal and ventral constrictions.

- Harengula konigsbergeri* (Weber and de Beaufort 1912)
Clupalosa lippa (Whitley 1931)
Harengula maccullochi Whitley 1931
Harengula macrolepis (Steindachner 1879)
Harengula ovalis (Bennett 1830)
Harengula vittata (Valenciennes 1847)

The last 11 species are Indo-Pacific and may all belong to *Clupalosa*.

I have tabulated 110 nominal species that appear to belong to these four genera, of which only about 43–51 species may be valid. There are many conflicting opinions and uncertainties concerning the synonymies of these nominal species. In listing the species above I have used and attempted to reconcile the works of Chan (MS), Fowler (1941), Herre (1953), Regan (1917), Rivas (1950), and Whitley (1940, 1941, 1948).

The separation of *Harengula* and *Sardinella* was discussed by Chan (MS), who was the first to emphasize the differences in the larger and more posterior of the two supramaxillaries in these two genera. Chan also detailed differences in scale sculpture between these genera and commented upon the two enlarged terminal anal fin rays in *Sardinella*. Whitehead (1962) suggested that *Harengula* might have a greater number of parietal striae than *Sardinella*; but this difference, if valid, is complex, because the number of parietal striae in *Harengula thrissina* progressively increases from about 5 at 50 mm S. L. to about 13 at 130 mm. Chan and previous authors were unaware of the hypomaxillary bones in American species assigned to *Harengula*, however, and considered *Harengula* in its broad sense to include the Indo-Pacific species which lack hypomaxillaries.

The phylogenetic significance of the hypomaxillary and its importance in the classification of the Clupeidae are subject to various interpretations. A thorough knowledge of the morphology of the genera and species of Clupeidae and of the origin and development of this bone will furnish a more definitive answer to these issues.

The hypomaxillary is a specialized structure that must have developed independently in two phyletic lines of the Clupeidae—in the typical herring genus, *Harengula*, and in *Pellona* and

Pliosteostoma of the group of clupeids with a high number of anal rays and greatly compressed bodies, sometimes referred to as "bloodless clupeids." It probably arose as a permanent splitting off of a portion of the maxillary premaxillary; it is less probable that its origin was the spontaneous development of a new site of ossification.

In *Aphredoderus* (Percopsiformes) and in certain species of Amblyopsidae (Amblyopsiformes) each premaxillary is divided distally into from 2 to about 7 distinct but closely associated parts of progressively decreasing size (Rosen, 1962). These smaller terminal portions of the premaxillaries were termed segments, and Rosen (1962:23) suggested that these segments produced a flexibility to the upper jaw in full extension of the mouth. This might indicate that these segments were developed in response to a need for additional flexibility, or that, after they had developed, additional flexibility was possible. The clupeid hypomaxillary undoubtedly developed independently from the premaxillary segments of *Aphredoderus* and the amblyopsids, and, if any such functionalism were once a factor in the origin of the hypomaxillary in these clupeids, it has subsequently been lost or occluded.

My studies have led me to believe that, within the two clupeid groups concerned, the hypomaxillary must be significant in indicating a distinct phylogenetic (and taxonomic) difference between the species which have it and those which lack it. Myers (1950) found the hypomaxillary present on one side and absent on the other in a large specimen of *Pellona* and questioned its significance; but in the hundreds of specimens of all species of *Pellona*, *Pliosteostoma*, and *Harengula* that I have examined both sides of the upper jaw have hypomaxillaries of similar size.

To stabilize the nomenclature until extant uncertainties are clarified, and because published generic names are available, I have proposed above that the presence of the hypomaxillary be regarded as a criterion of generic distinction and restriction of the genus *Harengula*.

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Review and Emendation of: Family Clupeidae
By Samuel F. Hildebrand
FREDERICK H. BERRY

REVIEW AND EMENDATION OF: FAMILY CLUPEIDAE, pp. 257-454. By Samuel F. Hildebrand, with emendations by others, and sections on *Harengula* by Luis R. Rivas and on *Dorosoma* by Robert R. Miller. (In) *Fishes of the Western North Atlantic*. Sears Foundation for Marine Research, New Haven, Connecticut, Memoir I, Part 3, 630 pp., Figs. 1-139. \$27.50. Publication date 1 March 1964 (1963 shown on title page).—Samuel F. Hildebrand (1883-1949) made some of the most significant contributions to our recent knowledge of taxonomy of American marine fishes: *The Fishes of Chesapeake Bay* (1928), *The Fishes of Tortugas* (1941), *The Marine Fishes of Panama* (1923-1928), and *A Descriptive Catalog of the Shore Fishes of Peru* (1946) are indispensable to students of tropical and subtropical marine fishes of the American continents. He participated in planning *The Fishes of the Western North Atlantic* and completed manuscripts for inclusion in this series on the families Engraulidae, Albulidae, Elopidae, and Clupeidae. The Clupeidae was completed last in 1948. In retrospect, it is unfortunate that these manuscripts were not published at that time. This would have facilitated our comprehension and study of these important fish groups.

In reality, it is still advantageous that this work has finally been made available—16 years later. Now, however, anyone who uses these accounts must realize that certain factors must be considered in evaluating them. (1) These accounts are in many instances out-of-date. Editor Y. H. Olsen implied (p. 110) that G. S. Myers had brought some of them up-to-date. Dr. Myers informs me that the appreciable effort he extended on revision of these manuscripts was done some 14 or 15 years ago, and that his more recent efforts, 2 years ago, were toward straightening out the proof. In the account of the Clupeidae, references to only about 30 studies published subsequent to 1948 have been inserted and over half of these relate to the account of the genus *Dorosoma*, recently revised (1960) and prepared for this volume by Robert R. Miller. (2) The Clupeidae section, especially, is a conglomerate of in-

dividual, and not necessarily compatible revisionary efforts. Footnote 1 acknowledges that this section was "Edited, with some revision and expansion, by George S. Myers, Henry B. Bigelow, Myvanwy M. Dick, and Yngve H. Olsen." Other footnotes specify or distinguish at least 13 comments by Myers and one each by Bigelow and Olsen.

There obviously have been many other changes or additions to Hildebrand's manuscript. I have been unable to locate a copy of Hildebrand's original manuscript, and it has been suggested that such may not now exist. To a serious student of Hildebrand's work, it would have been desirable to know which of Hildebrand's original thoughts or proclamations had been changed and by whom. Dr. Myers writes that this would now be impossible to determine, and I judge from his other comments that the original manuscript was much in need of revision before publication. There is no doubt that most of these changes have materially improved the publication. Myers knew certain of the genera better than Hildebrand, and if he had had an entirely free hand in adjusting the taxonomic structure (as by coauthorship), the entire section would have been even better. Additions to the bionomics of certain species, presumably by Dr. Bigelow have definitely added to the value of the accounts. A reasonable complaint with all this is that changes were not made in many instances where they should have been, and since we cannot distinguish in most instances where changes were or were not made, the portions ascribed to Hildebrand are no equal in quality or completeness.

Over half of Part 3 of *Fishes of the Western North Atlantic* is devoted to the partially outdated Hildebrand manuscripts. It would have been better if these accounts could have been more up-to-date; but ichthyology is benefited from their publication, even at this time, because they still represent the most comprehensive treatment yet published of these fishes. They furnish a point of departure for needed future study and revision.

This review is largely limited to the Clupeidae section of Part 3. Purposes of the

review are to incorporate the advanced ideas of certain publications not referred to in the text (from 1949 through 1964), to note other pertinent recent references, to point out several sections of the text where opinion may differ from that expressed, and to indicate certain areas of the text where additional study is most needed. Included are certain data from my own clupeid research and comments solicited from other workers active in this field.

This review will hopefully achieve another purpose. After a major group revision is published, there usually appear a number of notes, adding minor bits of knowledge, new species descriptions, range extensions, etc. Because this Clupeidae account is not up-to-date, there is already extant a wealth of material that could be published as a large number of notes. It is hoped that any such efforts will not be based on this FWNA account alone, but on all of the salient literature since 1948.

The following remarks on other sections of the *Isospondyli* are considered before initiating specific comments on the Clupeidae.

In the characterization of the suborders and families of the order *Isospondyli*, Bigelow (pp. 92 and 108) considered that the maxillaries did not enter the upper border of the mouth in *Albula*, *Pterothrissidae*, *Nematalosa*, and *Chanos*. The premaxillaries extend farther posteriorly in these fishes than is the usual case in *isospondyliids*, but the maxillaries do enter the gape when the mouth is open. They may all be similar to *Albula*, in which the premaxillaries occupy only the anterior part of the gape in small juveniles and then continue to grow posteriorly through the adult stage (Berry 1964, *Copeia* 1964 (2):377-378).

A confusing character is introduced by Bigelow in the key to the suborders of *Isospondyli* (pp. 95 and 149) where *Bathylaconoidea* is separated in part from Clupeoidea and 3 other suborders by the nature of the association of the upper branchiostegal ray with the subopercular. Comparison of a specimen of *Bathylaco* from the eastern Pacific Ocean (Berry and Perkins ms) with 3 common genera of Clupeidae (*Brevoortia*, *Harengula*, and *Opisthonema*) shows the association of these elements to be very similar: in both groups the upper medial surface of the uppermost branchiostegal is

attached by membrane to the ventromedial side of the subopercular and interopercular "thus taking part in formation of gill cover," and the branchiostegal rays of the clupeids are more "plate-like" than they are in *Bathylaco*.

For the suborder Clupeoidea, Bigelow (p. 148) erroneously gives "Pelvic fins no farther forward than midlength of body . . .," for Fig. 25 (p. 156) shows the pelvis of *Anchovia clupeoides* to be closer to the tip of the snout than to the end of the anal fin. It can be added to this account that scales are also pectinate in the eastern Atlantic genus *Ethmalosa*.

Other misleading characters concern the characterization and key distinctions of the suborder Clupeoidea (pp. 95, 96, and 149): the dorsal contour of the snout is *not* always convex (see Fig. 109); the branchiostegal rays *can* be plate-like (see Fig. 94 and others).

Chirocentridae is listed as a distinct family on p. 149, is not listed in the key to the families of Clupeoidea on p. 150, and is given as a subfamily of Clupeidae on p. 262.

The primary common names given for the clupeoid species follow the common names recommended by the American Fisheries Society (1960, *Spec. Publ. No. 2*), with the exception of that for *Alosa pseudoharengus*. I disagree with the change of the common name of this species, for many years most generally known as alewife, to "Grayback" (p. 332).

The generic name *Tarpon* is retained (p. 112) in preference to the currently accepted *Megalops* (as by Wade 1962, *Bull. Mar. Sci. Gulf Caribb.* 12 (4):545-622). P. J. P. Whitehead (personal communication) notes that the presence of a swim bladder vesicle within the skull (opisthotic) of *Megalops* is not mentioned, and he opines that this alone should justify the separation of *Elops* and *Megalops* at the family level.

For *Albula vulpes* (p. 134) a reference as recent as 1961 is included, but for *Elops saurus* (p. 124) the latest reference is 1943. See Gehringer 1959, *U. S. Fish and Wildl. Serv. Fish. Bull.* no. 155, vol. 59, pp. 619-647 (early development and metamorphosis of *E. saurus*); Whitehead 1962, *Ann. Mag. Nat. Hist.* 54 (4):321-329 (species of *Elops*). Bigelow and Hildebrand contended that *Albula* lacked the gular plate present in *Megalops* and *Elops* (pp. 107, 108, 132). P. J. P. Whitehead informs me that he has

confirmed the presence of a gular plate in *Albula* as described by Nybelin (1960, *Nature* 188:78), that it is not visible externally, but can be found by dissection in specimens of 130 mm SL.

The synonymy of the Atlantic *Dixonina nemoptera* with the Pacific *D. pacifica*, proposed by Hildebrand (pp. 143-145) on very casual and presumptive grounds, is to be questioned. The original distinction of *D. pacifica* was also somewhat presumptive, but, once a specific name has been proposed that distinguishes a geographically isolated form from its congener, it is usually better (certainly in this instance) to retain the name until adequate material is available and adequate assessment is made to properly define the relationship.

Engraulidae (pp. 152-249). The following notes on this portion of the publication were furnished by P. J. P. Whitehead (personal communication). The lateral line in engraulids is either absent or so poorly developed that it cannot be seen, as is correctly stated on p. 152, not well developed as stated on p. 148. The statement on p. 152, "Chest and abdomen in American species often carinate, without bony serrae," while correct, tends to be misleading. All New World engraulids lack abdominal scutes (except for the single pelvic scute, which bears no keel or spine). With the exception of *Engraulis* and 1 species of *Stolephorus*, all Old World engraulids possess abdominal scutes, usually keeled and with posterior spines. Luminescent organs were not recorded to occur in this family (pp. 148, 152), but pearly spots on the flanks and elsewhere of *Coilia margaritifera* are similar to the luminescent organs that were recently documented in *Coilia dussumieri* by Haneda (1961, *Sci. Rep. Yokosuka Mus.* 6:45-50). The genus *Engraulis* is now known to occur in the western North Atlantic Ocean. *Anchoviella eurystole* (Swain and Meek) (p. 208) and *A. estanquae* Hildebrand (p. 211) (orthography corrected by Hubbs 1953, *Copeia* 1953 (3):193-194) are both members of *Engraulis*, closely resembling the European anchovy, *E. encrasicolus* (Linnaeus) (Whitehead, 1964, *Zool. Zh.* 43 (6):879-888). "Although superficially alike, the two genera can be separated on the following characters:

A. *Engraulis*

1. Posterior tips of frontals meeting or almost meeting in midline; pos-

terior frontal fontanelles square or rectangular in juveniles (40-60 mm SL) but virtually occluded in fishes over 80 mm.

2. Anal origin up to one eye diameter behind base of last dorsal ray.
3. Pseudobranch long, exceeding eye diameter, extending posteriorly onto inner face of operculum and beyond hyomandibular facet; 25-40 pseudobranchial filaments.

B. *Anchoviella*

1. Posterior tips of frontals widely separated in the midline posteriorly, exposing a pair of triangular fontanelles, retained in adults.
2. Anal origin under or only very slightly behind dorsal base.
3. Pseudobranch short, equal to or shorter than eye diameter, barely reaching onto inner face of operculum, not reaching beyond hyomandibular facet; about 15-25 pseudobranchial filaments."

Clupeidae (p. 257). Estimates on the numbers of genera and species in the family vary: about 70 genera and perhaps 150 or more species was Hildebrand's estimate; 50 genera and about 190 species was given by Svetovidov (1952:35); and a recent, finite count of 49 genera and 187 species was recorded by Yudanov (1961, *Voprosy Ikhtiol.* 1 (2):221-230). There are 35 species covered in the FWNA account.

The family limits of the Clupeidae have the broad interpretation in this work of including as subfamilies the Dussumieriinae, the Dorosomatinae, the Pristigasterinae, the Chirocentrinae, and the Clupeinae. This interpretation is not definitive, because various authors continue to recognize the Dussumieriinae, the Dorosomatinae, and especially the Chirocentrinae as distinct families.

The key to the Clupeidae is partially misleading in the first couplet (1a vs. 1b), because in many adult specimens of *Clupea* and *Sardinella* the chest and abdomen are only "little compressed" and the chest and abdomen are not "compressed into a sharp keel." The stomach of *Opisthonema* and other nondorosomatid genera can be gizzard-like (3a vs. 3b).

The methods of counting used for this family warrant comment: Gill raker counts are said to include the number present on

the first gill arch (p. 259). Presumably this would be the total count including both upper and lower limbs, but the treatments under the individual accounts are not always clear. In many instances the count given is specified to be limited to the lower limb (as *Sardinella anchovia*, p. 402), but in others, where a comparable count would be expected (as *S. brasiliensis*, p. 408) this is not specified, and presumably the count given could be the total count. In footnote 47 (p. 398): "It was found necessary to remove the gill rakers from the arch to make an accurate count"—this is regrettable. In most circumstances, the gill rakers, and especially the gill arch, should *not* be removed from museum specimens, and extreme care and intimate knowledge of the species' morphology should be exercised in any excision. When the anteriormost rakers cannot be readily seen, fewer characters are damaged if the branchiostegal membrane is cut away from the isthmus on the right side. The use of compressed air usually increases the speed and accuracy of gill raker counts. For suggestions on other problems and methods of counting gill rakers in clupeids, especially those in which the number of gill rakers continues to increase with increase in body size, see Berry and Barrett (1963, *Bull. Inter-Am. Trop. Tuna Comm.* 7 (2):128-130). Also see their account (p. 128) for discussion of a practical problem frequently encountered in making standard length measurements of clupeids. The fin rays count stated (p. 259) to be used for the family was, "includes all rays, whether rudimentary, simple, or branched; the last ray, even though nearly double, counted as one." However, fin counting methods used for the genera *Dorosoma* and *Harengula*, although not so stated, were obviously different (see Miller 1950: 388, Rivas 1950:276, and Storey 1938:7). This difference may also apply to other genera and species. Dorsal and anal fin rays are relatively difficult to count in many species of clupeids, and accurate counts can frequently be made only by dissection or staining. Because ray counts of these fins are not of tremendous taxonomic importance in many species, it might be better not to record dorsal and anal fin ray counts for these species, if the counts cannot be made accurately. An attempt to standardize methods of certain measurements and counts for clupeid species was prepared by F. A. O.

(1957, *Gen. Fish. Coun. Med., Stud. & Rev.* 1:1-35). This was a laudable attempt, but certain sections are now in need of revision.

Recent references to the family, subfamilies, or 2 or more genera of Clupeidae: Fowler 1948, *Arq. Zool. S. Paulo* 6:1-204 (new subfamilies Brevoortinae and Ilshinae). Weibezahn 1952, *Bol. Pesc. Caracas* 3:1-21 (key to Venezuelan Clupeidae). Hildebrand 1955, *Pub. Inst. Mar. Sci.* 4 (1):199-200 (notes on *Sardinella anchovia*, *Harengula pensacolata*, *Opisthonema oglinum*, and *Brevoortia gunteri* from Gulf of Campeche). Fowler 1958, *Notulae Naturae* 310:1-16 (new subfamilies Dussumieriinae, Gudusiinae, and Opisthoneminae). Springer and Woodburn 1960, *Fla. St. Bd. Cons. Prof. Pap. Ser.* 1:16-20 (Tampa Bay area; growth of young *Brevoortia patronus* and *Harengula pensacolata*; ecological notes on *B. smithi*, *Dorosoma petenense*, *Opisthonema oglinum*, *Etrumeus sadina*, and *Sardinella anchovia*). Gosline 1960, *Bull. Brit. Mus. Nat. Hist.* 6 (6):327-365 (caudal skeleton of Isospondyli and synopsis of superfamilies). Suárez Caabro, Duarte Bello, and Requena 1961, *Inst. Cubano Invest. Tecn., Min. Indust. Cuba* 19:1-87 (biology and technology of *Harengula pensacolata cubana* and *H. humeralis* in Cuba; taxonomic notes on *H. clupeiola*, *H. p. pinensis*, *Opisthonema oglinum*, and *Sardinella anchovia* from Cuba). Gosline 1961, *Smithson. Misc. Coll.* 142 (3): 1-42 (osteological characters of modern lower teleosts). Reintjes and June 1961, *Proc. Gulf Caribb. Fish. Inst. 13th Ann. Sess.* pp. 62-66 (fishery potential, Gulf of Mexico, *Brevoortia patronus*, *Opisthonema oglinum*, *Harengula pensacolata*, *Etrumeus sadina*, *Sardinella anchovia*). Mairs and Sindermann 1962, *Biol. Bull.* 123 (2):330-343 (serological techniques and comparison of *Alosa pseudoharengus*, *A. aestivalis*, *A. sapidissima*, *Clupea harengus harengus*, and *Brevoortia tyrannus*). Whitehead 1963, *Ann. Mag. Nat. Hist.* 13, 5:737-750 (synopsis of suborders Elopoidi and Clupeoidi; characters of posterior frontal fontanelles, pelvic scutes, pelvic splint bones).

Dussumieriinae: This subfamily was recently reviewed on a worldwide basis by Whitehead (1963, *Bull. Brit. Mus. Nat. Hist.* 10 (6):307-380), who allowably considered it as a distinct family. Whitehead (1963:320-328) changed the specific name of the monotypic *Etrumeus* to *E. teres* (DeKay), con-

sidering the more frequently used name, *E. sadina* (Mitchill), to be a *nomen dubium*. For the other western Atlantic representative of this group, Jenkinsia, Whitehead recognized two species, *J. lamprotaenia* and *J. majua* each considered to be composed of 2 subspecies. These 2 species are primarily distinguished by a premaxillary character (*lamprotaenia* toothed, *majua* edentulous). Both of the subspecies pairs he recognized were separated by slight differences in gill raker numbers (a character known to be subject to environmental-geographical modification in many clupeids), and the range of each subspecies of these 2 species overlaps. The nominal endemic Bermuda species, *J. viridis* Bean (= *J. bermudana* Rivas, synonymy recognized independently by Collette 1962, *Copeia* 1962 (3):659 and Hildebrand in manuscript ca. 1948) was considered by Whitehead to also occur at Venezuela and to be a subspecies of *J. lamprotaenia*.

Clupea (p. 274). Svetovidov (1952:118-119) considered *C. harengus* to consist of 2 subspecies, *C. h. harengus* and *C. h. pallasi*. He divided each of these subspecies into "a number of forms," to which he applied latinized quadrinomials, for example, *Clupea harengus pallasi marisalbi*. Quadrinomials are not recognized by the International Code of Zoological Nomenclature (London 1961), and the subspecies designations are not recognized by most current authors. A review of recent publications shows that the Atlantic population is most generally referred to as *C. harengus* (references given below), and the Pacific population most generally as *C. pallasi* (Roedel 1962, *Calif. Fish & Game* 48 (1):23).

Clupea has received more scientific attention than any other genus of the Clupeidae. Bernard E. Skud, who has reviewed the *Clupea* account in FWNA, has furnished the following comments and a list of the most important publications on Atlantic *Clupea* and has stated that the FWNA account of *Clupea* needs a complete rewriting to update the material—especially since most of the text refers to information on the European herring (personal communication). References to spawning (pp. 277, 280-281) should include mention of recent data on Georges Bank, Canadian Maritimes, and Newfoundland, as by Tibbo, Scattergood, Olsen, etc. Larval studies on Georges Bank and the Bay of Fundy should be included (pp. 278-279).

Recent Russian work has added much to our knowledge on habits (p. 281). New data on swimming speed as well as other information on behavior could be added (p. 282). There are several recent papers on migrations of Gulf of Maine herring; the account on p. 283 suggests that individual fish remain inshore all summer, but recent U. S. and Canadian papers on tagging show that this is not the case. Several recent North American references are now available on food and feeding that offer much greater detail (p. 283). Unpublished work at Woods Hole indicates that cod and haddock are unimportant as predators (p. 284). Our knowledge on parasites and diseases has been greatly extended by Scattergood and Sindermann (pp. 285-286). Methods of fishing should include Russian activities (p. 290). Recent references: Scattergood 1948, *U. S. Fish and Wildl. Serv. Spec. Sci. Rept.* no. 58 (fungus in NW Atlantic herring). Sanders 1952, *Bull. Bingham Oceanogr. Coll.* 13 (3):220-237 (herring of Block Island Sound). Harder 1953, *Z. Morph. Okol.* 42:209-224 (body form and growth relation in *C. harengus*). Huntsman 1953, *J. Fish. Res. Bd. Can.* 10 (1):1-50 (movements and decline of large Quoddy herring). Sindermann and Scattergood 1954, *Res. Bull. Dept. Sea and Shore Fish. Maine* no. 19 (disease in *C. harengus*). Jean 1956, *Contr. Dept. Pech. Quebec* no. 49 (spring and fall spawning herring). Sindermann 1956, *Res. Bull. Dept. Sea and Shore Fish. Maine* no. 25 (fungus disease and resultant mortalities of herring). Tibbo 1956, *J. Fish. Res. Bd. Can.* 13 (4):449-466 (Newfoundland herring populations); 1957, *Bull. Fish. Res. Bd. Can.* no. 111, pp. 139-151 (biology of Nova Scotia herring); 1957, *Bull. Fish. Res. Bd. Can.* no. 111, pp. 153-164 (Newfoundland herring populations). Day 1957, *Bull. Fish. Res. Bd. Can.* no. 111, pp. 103-119, 121-137 (Gulf of St. Lawrence herring populations). Sindermann 1957, *Res. Bull. Dept. Sea and Shore Fish. Maine* no. 29 (disease of immature herring); 1958, *Trans. N. Am. Wildl. Conf.* pp. 349-360 (epizootic in herring). Tibbo et al. 1958, *J. Fish. Res. Bd. Can.* 15 (6):1451-1469 (distribution of larval herring). McKenzie and Skud 1958, *J. Fish. Res. Bd. Can.* 15 (6):1329-1343 (herring migrations). Scattergood, Sindermann, and Skud 1959, *Trans. Am. Fish. Soc.* 88 (3):164-168 (herring spawning). Scattergood and Tibbo 1959, *Bull. Fish. Res. Bd.*

Can. no. 121 (northwest Atlantic herring fishery). Sindermann and Mairs 1959, *Copeia* 1959 (4): 228-232 (blood groups in herring). Brawn 1960, *J. Fish. Res. Bd. Can.* 17 (5): 699-711 (seasonal and diurnal vertical distribution of herring). International Pas-samaquoddy Fisheries Board 1960, *U. S. Fish and Wildl. Serv. Spec. Sci. Rept. Fish.* no. 360 (biological and economic studies). Legare 1960, *J. Fish. Res. Bd. Can.* 17 (3): 409-448 (plankton food of herring). Tibbo and Legare 1960, *J. Fish. Res. Bd. Can.* 17 (6): 933-942 (larval herring). Boyar 1961, *Trans. Am. Fish. Soc.* 90 (1): 21-26 (swimming speed of immature herring). Colton 1961, *J. du Conseil* 26 (2): 180-190 (larval herring sampling methods and distribution). McKenzie and Tibbo 1961, *J. Fish. Res. Bd. Can.* 18 (2): 221-252 (herring movements). Olsen 1961, *J. Fish. Res. Bd. Can.* 18 (1): 31-46 (Newfoundland herring biology). Benko and Wilson 1962, *Trudy PINRO* (Moscow) ser. XIV (herring feeding and physiological state). Judanov 1962, *Sovetskije ribochozyaistvennie issledovania v severozapadnoi chasti Atlanticheskogo okeana* (Moscow) (the clupeoids of the NW Atlantic); 1963, *Ribnoie Chozyaistvo* (Moscow) no. 2 (NW Atlantic herring fishing); 1963, *Ribnoie Chozyaistvo* (Moscow) no. 4 (features of biology of NW Atlantic herring). Fridliand, Erohin, and Yakovchuk 1963, *Trudy BaltNIRO* (Kaliningrad) ser. 9 (biology and stocks of Nova Scotian herring). Tibbo and Graham 1963, *J. Fish. Res. Bd. Can.* 20 (2): 435-449 (postepizootic biological changes in herring stocks). Watson 1963, *U. S. Fish and Wildl. Serv. Spec. Sci. Rept. Fish.* no. 451 (immature herring tagging method); 1964, *Trans. Am. Fish. Soc.* 93 (1): 11-20 (otolith aging of young herring). McKenzie 1964, *J. Fish. Res. Bd. Can.* 21 (1): 203-204 (herring spawning off SW Nova Scotia). Graham and Boyar 1964, *ICNAF Environ. Symp. Contr.* no. E-7 ser. no. 1259, in press (ecology of herring larvae in Maine coastal waters).

There are in past literature a number of conflicting opinions regarding the synonymy and proper specific names that apply to the clupeids. Such an example occurs with *Alosa aestivalis* (Hildebrand, pp. 324 and 331). Bean (1901, 7th Rept. N. Y. St. For. Fish & Game Comm., p. 304) used the name *Pomolobus cyanonoton* (Storer 1848) for this species, because he considered Mitchill's *aestivalis* to more likely be a synonym of

A. mediocris (Mitchill). Hildebrand (pp. 324-332), and most others, have accepted Mitchill's name, and Hildebrand considered Storer's name unidentifiable, and listed it as a doubtful reference to *A. aestivalis*. The type specimens of the new species of North American clupeids described in the first half of the nineteenth century by Wilson, Mitchill, LeSueur, DeKay, and Storer all appear to be lost, if such specimens were ever placed in museums. These early descriptions upon which we base our scientific names are often inadequate to determine which species the author had—this is especially true in a group such as *Alosa* where our current taxonomic distinctions are still incomplete. The uncertainties of these early and inadequately described species furnish opportunity for a variety of opinionated and vacillating name changes. Needed are a comprehensive conception of the species that exist, a complete and conscientious appraisal of the early descriptions, and a subsequent designation of neotypes for all of these nominal species. This will firmly fix the names for these species. Such designations should, wherever possible, be so constructed that they will retain for each valid species the name that has been in general use. Until this is done, it can be suggested that the names in general use be retained, and not subjected to opinionated change.

Alosa and *Pomolobus* (pp. 293 and 312). *Pomolobus* has been synonymized under *Alosa*, most recently by Svetovidov (1964, *Copeia* 1964 (1): 118-132). Previous characters suggested to distinguish the 2 nominal genera were largely relative, variable, and inadequate. After an initial study of the genus, I feel that anyone can identify adults of the 6 American species with a reasonable amount of accuracy—if he has become familiar with the species and the literature and has comparative material. But small specimens (up to 6 in. long) are difficult to identify using Hildebrand's or any other account; I have seen numerous misidentified specimens in collections; and it is obvious that more detailed and concise keys and descriptions are needed. Hildebrand alluded to this problem in his comments on page 330. Four of the species exist as 2 geographically separated "pairs": *A. sapidissima* and *A. alabamiae*; *A. mediocris* and *A. chrysochloris*; and the species within each pair can be "identified" on the basis of their

location of capture (unpublished differences of opinion exist on the status of the nominal species *A. alabamiae* and *A. ohioensis*). For the 4 species occurring in the Atlantic drainage, *A. mediocris* can be distinguished to very small sizes by its low number of gill rakers (<24), and numbers of vertebrae suggest a method of separation of problem specimens of the other 3 species (*A. pseudoharengus* 46–50, *A. aestivalis* 49–53, *A. sapidissima* 54–59). The ranges for 2 of the species as reported by Hildebrand can be corrected. *A. alabamiae* (p. 311) extends southeastward to the Santa Fe River of the Suwanee River drainage (specimens FSM 8539; Hellier, thesis 1955, Univ. Florida, p. 29). Hildebrand discounted, I believe justifiably, records of *A. pseudoharengus* from Florida (p. 340), but restricted its southern range to North Carolina; Robert R. Miller (personal communication) has determined that *A. pseudoharengus* occurs at least as far south as South Carolina. Certain features detract from the Hildebrand account: *Alosa* was separated in part from *Pomolobus* (p. 260) on the basis of the length vs. depth of the cheek, but this is a difficult character to assess, and only the cheek depth measurement is given (p. 259). An error on p. 314 shows a gill raker range of 38–41, where 38–52 was intended. Three different ranges of gill raker numbers are given for *A. aestivalis* on pp. 314 and 325: 41–52, 41–51, and 42–52. Recent references: Walburg 1955, *U. S. Fish and Wildl. Serv. Res. Rept.* 38:1–17 (relative abundance, *A. sapidissima*). Graham 1956, *Univ. Toronto Biol. Ser.* 62:1–43 (growth study, *A. pseudoharengus*). Dence 1956, *Copeia* 1956 (2):155–158 (concretions, *A. pseudoharengus*). Miller 1957, *Trans. Am. Fish. Soc.* 86:97–111 (origin and dispersal, *A. pseudoharengus*, Great Lakes). Mansueti 1958, *Nature Mag.* 51 (7):351–354 (spawning, early development, *A. mediocris*). Talbot and Sykes 1958, *U. S. Fish and Wildl. Serv. Fish. Bull.* no. 142, vol. 58, pp. 473–490 (migrations, *A. sapidissima*). Hill 1959, *U. S. Fish and Wildl. Serv. Fish. Bull.* no. 147, vol. 59, pp. 269–286 (statistical analysis of races, *A. sapidissima*). Walburg 1960, *U. S. Fish and Wildl. Serv. Fish. Bull.* no. 177, vol. 60, pp. 487–501 (fishery, abundance, life history, *A. sapidissima*, St. Johns River, Fla.). Massmann 1961, *Chesapeake Sci.* 2 (1/2):76–81 (1814–1824 Potomac River fishery for *A. aestivalis* and *A. pseudoharengus*). Dow

1962, *J. Conseil Perm. Internat. Explor. Mer* 27 (1):77–80 (swimming speed, *A. pseudoharengus*). Mansueti 1962, *Chesapeake Sci.* 3 (3):173–205 (eggs, larvae, and early development, *A. mediocris*; egg sizes of other clupeids).

Brevoortia (p. 342). Hildebrand recognized 5 western North Atlantic species and 2 western South Atlantic species. Pertinent comments on this have been furnished by John W. Reintjes (personal communication): (1) *B. breviceaudata* is a nominal species known only from the type specimens collected from Noank, Connecticut. The types differ from *B. tyrannus* in having shorter heads, maxillaries, mandibles, pectoral and caudal fins, and smaller eyes. There are 2 spawning periods in the vicinity of Long Island, one in the spring, the other in the late summer. In some years, the young from the latter spawning survive and overwinter in the area. Yearling fish have been collected in this area by the Bureau of Commercial Fisheries that are unusual and appear stunted. Normally, yearling menhaden do not occur north of New Jersey, so the unusual yearlings from Long Island are probably resident survivors of the late summer spawning. It is probable that the type specimens of *B. breviceaudata* are *B. tyrannus* that were malformed by environmental stress and that the 2 species are synonymous. (2) The key to *Brevoortia* (pp. 344–346) will separate the 2 pairs of North American menhaden (*tyrannus*/*patronus* and *smithi*/*gunteri*) by scale count, shape of ventral fins, opercular striations, and secondary body spots. All counts and measurements overlap within each pair making species identity, without using geographic range, very precarious. The least overlap occurs in total vertebral counts which will separate about 9 out of 10 specimens within each pair (*B. tyrannus* usually 47 to 49 and modally 48 vertebrae and *B. patronus* usually 45 or 46; *B. smithi* usually 45 or 46 and *B. gunteri* usually 43 or 44). However, from our knowledge of geographical distribution, size composition, life history, and behavior, these four nominal species certainly appear to be valid. (3) The 2 South American species, *B. pectinata* and *B. aurea*, are very imperfectly known, and Hildebrand's conclusions on their taxonomy should be accepted until more specimens become available and have been

adequately studied. Recently acquired specimens from Argentina appear to be *B. aurea*. Hildebrand's specimen records indicated that the 2 species were allopatric with *B. pectinata* occurring only in Argentina and *B. aurea* occurring only in Brazil southward to Rio de Janeiro. Recent references: June 1956, *Proc. Gulf Caribb. Fish. Inst. 9th Ann. Sess.* pp. 99–106 (synopsis of biological investigation, *B. patronus*). Suttkus 1956, *Trans. 21st N. Am. Wildl. Conf.* pp. 390–407 (early life history, *B. patronus* in Louisiana; photographs of young). Suttkus 1958, *Trans. 23rd N. Am. Wildl. Conf.* pp. 401–410 (distribution of *B. patronus*, *B. gunteri*, and *B. smithi*, Gulf of Mexico; comparison of *B. smithi* from Atlantic and Gulf of Mexico; comparison of *B. smithi* and *B. gunteri*). June 1958, *Rapp. et Proc.-Verb. Cons. Internat. Explor. Mer* 143 (2):26–35 (variation of vertebrae, ventral scutes, dorsal and pectoral rays, *B. tyrannus*). June and Chamberlin 1959, *Proc. Gulf Caribb. Fish. Inst. 11th Ann. Sess.* pp. 41–45 (life history, *B. tyrannus*). Reintjes 1960, *Proc. Gulf Caribb. Fish. Inst. 12th Ann. Sess.* pp. 31–35 (*Brevoortia* distributed continuously around the Florida peninsula). Reintjes et al. 1960, *U. S. Fish and Wildl. Serv. Fish. Bull.* no. 170, vol. 60, pp. 297–322 (annotated bibliography, biology of *Brevoortia*). June and Roithmayr 1960, *U. S. Fish and Wildl. Serv. Fish. Bull.* no. 171, vol. 60, pp. 323–342 (age determination from scales, *B. tyrannus*). Christmas and Gunter 1960, *Trans. Am. Fish. Soc.* 89 (4):338–343 (distribution, biology, *B. patronus*, *B. gunteri*, and *B. smithi*, the Gulf of Mexico; morphological comparison, *B. gunteri* and *B. smithi*). Gunter and Christmas 1960, *U. S. Fish and Wildl. Serv. Spec. Sci. Rept. Fish.* 363:1–31 (bibliography on menhaden). Gunter and Demoran 1961, *Copeia* 1961 (1):39–42 (lateral lines and undescribed cephalic sensory area, *B. patronus*). Suttkus and Sundararaj 1961, *Tulane Stud. Zool.* 8 (6):177–182 (fecundity and reproduction, *B. patronus*). Monod 1961, *Bull. Inst. Français Afrique Noire, Ser. A, Sci. Nat.* 23 (2):506–547 (morphological comparison, *B. tyrannus* and *Ethmalosa fimbriata*). Reintjes 1962, *U. S. Fish and Wildl. Serv. Fish. Bull.* no. 202, vol. 62, pp. 93–102 (eggs and larvae, *B. smithi*). Sutherland 1963, *U. S. Fish and Wildl. Serv. Spec. Sci. Rept. Fish.* 435:1–21 (vertebrae, *B. tyrannus*). Roithmayr and Waller 1963, *Trans. Am. Fish. Soc.* 92

(3):301–302 (*B. patronus*, apparent winter movement to deeper water). Reintjes 1964, *Proc. Gulf Caribb. Fish. Inst. 16th Ann. Sess.* pp. 108–113 (distribution and seasonal occurrence in Florida, *B. tyrannus*, *B. smithi*, *B. patronus*). Recent references on fishery statistics of menhaden: McHugh et al. 1959, *Limn. and Oceanogr.* 4 (2):145–162. June and Reintjes 1959, *U. S. Fish and Wildl. Serv. Spec. Sci. Rept. Fish.* 317; 1960, *ibid.* 336. June 1961, *ibid.* 373. Roithmayr 1963, *ibid.* 434. June and Nicholson 1964, *ibid.* 446.

Opisthonema (p. 380). This genus was recently revised by Berry and Barrett (1963, *op. cit.*), largely on the basis of gill raker complements. Four species were determined to exist in the eastern Pacific Ocean (subsequent comments on this to the contrary in Annual Report of the Inter-American Tropical Tuna Commission for the year 1962, pp. 86–89, have later been found to be invalid). Only the single recognized species, *O. oglinum*, was considered to exist in the western Atlantic Ocean. Certain morphological differences were found between specimens from various areas of the western Atlantic Ocean, but none that could be considered to be of specific or even subspecific magnitude.

Harengula and *Sardinella* (pp. 386 and 397). Several recent works will serve to clarify the relationships of these genera and another associated genus, *Herklotsichthys* Whitley. There are more than 100 nominal species in this group of 3 genera. The exact number of valid species and the correct generic allocation of these is most imperfectly known. Chan (*Jap. J. Ichthyol.*, in press) revised the Indo-Pacific species of *Sardinella* and clarified the distinctions between *Sardinella* and *Harengula* (*sensu lato*), especially with regard to scale sculpture and shape of the posterior supramaxillary. Berry (*Pacific Sci.*, in press) documented and named the supplemental bone (hypomaxillary) in the upper jaw of *Harengula* (*sensu stricto*), and restricted the genus to species (which are all American) possessing this bone, considering Indo-Pacific species that had previously been placed in *Harengula* to belong to another genus. Whitehead (1963, *Ann. Mag. Nat. Hist.* 13, 6:273–284) reported on the correct generic allocation of the Indo-West Pacific species the proper name of this genus (*Herklotsichthys*), and on the distinctive character of the number of longitudinal striae on the frontoparietal "wedge."

Harengula by Luis René Rivas (p. 386). This is, with 2 major exceptions, a review of Rivas' 1950 review of the genus—the most recent cited paper in the present account. The 6 subspecies Rivas described in 1950 for *H. pensacolae* (tabulated as 5 on p. 395) are here obviated in a paragraph on variation in which Rivas said "These slightly different forms broadly intergrade with one another." *H. callolepis* is placed in synonymy of *H. humeralis*, with no remarks documenting this action—thus reducing by one the number of endemic Bermudian fish species. *H. clupeiola* and *H. pensacolae* are very inadequately distinguished in the key and in the text descriptions—by characters that show an appreciable overlap. For *H. clupeiola* (p. 390) it is stated that one of the distinguishing characters is its slender body, but in the illustrations *H. pensacolae* (Fig. 97) has a slenderer body than *H. clupeiola* (Fig. 96). The northern limit of range of *H. pensacolae* is given as Cape Kennedy, Fla. John W. Reintjes (personal communication) points out that this species was recorded from Elizabeth City, New Jersey, by Fowler (1945, *Acad. Nat. Sci. Phila. Monogr.* 7:104) and that Earl E. Deubler has confirmed its occurrence at Morehead City, North Carolina.

Sardinella (p. 397). In recognizing 3 species of this genus from the western Atlantic Ocean, Hildebrand acknowledged that taxonomic problems still remain and that "further study will be required to determine the exact relationship." He declared that the number of gill rakers on the first arch seemed to be best diagnostic character, but, because there is an increase in number with age and growth, it is "necessary to compare the number present in specimens of nearly equal size." It should also be pointed out that environmental factors can affect the numbers of gill rakers, as well as certain body proportions (such as body width and depth and head length used in separating 2 of the species). While most other authors have used *S. aurita* (with *S. anchovia* in synonymy) as the name for the common western Atlantic *Sardinella*, and have considered this species to range into the Indo-West Pacific, Hildebrand (pp. 405–406) retained the prior opinion of W. H. Longley that *S. aurita* is confined to the eastern Atlantic Ocean, and that *S. anchovia* is the proper name for the western Atlantic species. I have examined western Atlantic

specimens that tend to be intermediate in the characters Hildebrand used to distinguish the Bermudian *S. pinnula* from *S. anchovia*, and reevaluation of these species is suggested. *Sardinia pseudohispanica* Poey, sometimes listed as *Clupanodon pseudohispanicus*, is given as a doubtful synonym of *Sardinella anchovia* (p. 407) with the suggestion that *S. anchovia* might be composed of separate subspecies or species in the northern and southern parts of the western Atlantic—if so, *anchovia* would apply to the southern form and *pseudohispanica* to the northern. Martin and Gonzalez used the name *Clupanodon pseudohispanica* for a *Sardinella* from Venezuela, although they recognized the uncertain application of this name (in Rose and Murphy 1960, *Proc. World Sci. Meet. Biol. Sardines Rel. Spp.*, vol. 3, F. A. O., Rome).

Rhinosardinia (p. 411). This genus is very inadequately known, but the treatment of the species by Hildebrand is certainly the clearest yet available. Hildebrand included this genus in the Pristigasterinae, while Regan (1917, *Ann. Mag. Nat. Hist.* 8, 19: 394) had related it to *Harengula*, *Sardinella*, and *Lile*, with which action Norman (1923, *Ann. Mag. Nat. Hist.* 9, 11:1–22) apparently agreed. Considering all characters of generic magnitude, *Rhinosardinia* seems to be closer to the Clupeinae than the Pristigasterinae. The sculpture on the scales is an unusual character that warrants further study.

Pristigasterinae: The most lucid and recent publication treating this subfamily is by Peterson (1958, *Bull. Inter-Amer. Trop. Tuna Comm.* 1 (5): 139–280), confined to the eastern Pacific species. Apparently, 8 genera could be recognized in this subfamily (with the last 3 not known from the western Atlantic): *Odontognathus*, *Ilisha*, *Pellona*, *Neopisthopterus*, *Pristigaster*, *Pliosteostoma*, *Raconda*, and *Opisthopterus*. The genus *Ilisha* was considered by Hildebrand and Myers (pp. 415–427) to include species with only a ligament (or unossified connective tissue) between the end of the premaxillary and the maxillary, *Ilisha* (*sensu stricto*), and those that have a bone (the hypomaxillary) in this position, *Pellona*. The phylogenetic significance of the hypomaxillary is subject to various interpretation, as is the presence or absence of pelvic fins and the lumping of *Ilisha* with *Pellona*. Two other genera of the Pristigasterinae are currently separated largely by this same character—the hypo-

maxillaries are lacking in *Odontognathus* and present in *Pliosteostoma*. Some workers will prefer to use this character in distinguishing the 4 generic groups concerned (*Ilisha* and *Pellona*; *Odontognathus* and *Pliosteostoma*). Norman (1923:17) created the genus *Neosteus* for the species of Pristigasterinae possessing pelvic fins and hypomaxillaries; but, according to the generic synonymy given by Hildebrand (pp. 415-416), the earliest name for this genus is *Pellona*, with the type species *Pellona orbignyana* Valenciennes 1847 (= *Pristigaster flavipinnis* Valenciennes 1839), known only from Buenos Aires. With *Rhinosardinia* excluded, the following key is proposed to distinguish the 8 genera of Pristigasterinae:

- A. Hypomaxillary present B.
- AA. Hypomaxillary absent C.
- B. Pelvic fins present
..... *Pellona* Valenciennes 1847.
- BB. Pelvic fins absent
..... *Pliosteostoma* Norman 1923.
- C. Pelvic fins present
..... *Ilisha* Richardson 1846.
- CC. Pelvic fins absent D.
- D. Dorsal fin absent
..... *Raconda* Gray 1831.
- DD. Dorsal fin present E.
- E. Maxillary greatly elongated, extending to gill opening or beyond (at about 100 mm SL and larger)
..... *Odontognathus* Lacépède 1800.
- EE. Maxillary not extending beyond vertical of middle of eye F.
- F. Maxillary overlapping distal end of premaxillary
..... *Neoopisthopecterus* Hildebrand 1948.
- FF. Maxillary separated from distal end of premaxillary G.
- G. Body elongate, abdominal profile not very convex; dorsal fin origin on posterior half of body
..... *Opisthopecterus* Gill 1861.
- GG. Body very deep, abdominal profile very convex; dorsal fin origin on anterior third of body
..... *Pristigaster* Cuvier 1817.

Following this interpretation, *Ilisha amazonica* is the only western Atlantic species retained in this genus; and *flavipinnis*, *altamazonica*, *castelnaeana*, *harroweri*, and

narragansetae are included in *Pellona*. For *Pellona narragansetae* (Fowler) (pp. 426-427) Hildebrand remarked that the holotype and only known specimen was "purported to have been taken at Newport, R. I.," and that the genus [as *Ilisha* by Hildebrand] was not otherwise known from north of Trinidad and Panama. The locality data given for this species are certainly unusual and may be in error. Carter R. Gilbert has sent me specimens of *Pellona harroweri*, collected at Tortuguero, Costa Rica, in August 1963 (FSM 10761), that represent an extension of the known range of this species. Recent reference: Boeseman 1956, *Zool. Meded.* 34: 184 (*P. harroweri*, as *I. argentata*, from Surinam).

Pristigaster (p. 428): Characterized in part by "the several short spines on the median line of the back between the occiput and origin of dorsal." *Pristigaster cayana* has at least 5 pterygiophores (supraneurals) in advance of the dorsal fin. The above "characterization" undoubtedly refers to the protrusion of these internal bones above the dorsal profile, probably in a slightly shrunken or dried specimen. Recent reference: Tucker 1954, *Bull. Brit. Mus. Nat. Hist.* 2:211-214 (synonymy of *P. cayanus*).

Odontognathus (p. 430). Warren Freifhofer and I have found that a suggested abnormality in the ventral scutes of *O. mucronatus* represents a normal and very distinctive character of this species. Scutes anterior to the cleithrum are normal in size and spacing. These are followed by a short scuteless space and smaller, less regular scutes. The posterior pleural ribs of this species are peculiarly modified with dorso-lateral bulbous expansions which apparently accommodate extensions of the air bladder. The excessive elongation of the maxillaries is an ontogenetic process—in small specimens each maxillary extends posteriad to below the eye, at about 55 to 75 mm SL the posterior portion begins to elongate, and by about 100 to 110 mm SL this extends to the opercular margin or beyond. Small specimens of *Odontognathus* can generally be distinguished from related genera by the interruption in ventral scutes of *O. mucronatus* and the serrated margins of the posterior ventral scutes of *O. panamensis* (eastern Pacific) and *O. compressus*. These serrated scutes apparently persist in *Odontognathus compressus* and *O. panamensis*; Peterson

(1956:181, 203) reported such serrated scutes to be present in small specimens of the eastern Pacific *Opisthopterus dovi* (26 to 40 mm) but to be absent in larger specimens (71 to 195 mm). Carter R. Gilbert has recently identified specimens of *O. compressus*, collected at Tortuguero, Costa Rica (FSM 10760), that extend the known range of this species. Recent reference: Boeseman 1952, *Zool. Meded.* 31:184 (*O. mucronatus* from Surinam).

Lile Jordan and Evermann, little known in the Atlantic, is not included in the Hildebrand account, presumably because known records are from south of the area of coverage adopted by the series (the Amazon). *Lile piquitinga* was recorded from the coast of Brazil and *L. platana* was described from La Plata (Regan 1917, *Ann. Mag. Nat. Hist.* 8, 19:393-394).

Dorosoma by Robert Rush Miller (p. 443). This is essentially a brief condensation of Miller's 1960 publication on systematics and biology of the gizzard shad. Refer to that publication for additional information on *D. cepedianum* and keys to the Dorosomatinae and *Dorosoma* (1960, *U. S. Fish and Wildl. Serv. Fish. Bull.* no. 173, vol. 60, pp. 371-392). Miller cited the 1960 publication of Minckley and Krumholz (*Zoologica* 44 (4):171-180), but did not comment upon their contention of the validity of the genus *Signalosa*.

Miscellaneous corrections: p. 259, *Dussumieriinae* correct spelling; p. 263, Mitchell should be in parentheses as author of *Etrumeus sadina*; p. 293, Linck correct spelling; p. 296, "about 600 mm" should read "about 760 mm"; p. 343, footnote 36, correct citation is Ginsburg 1952, *J. Wash. Acad. Sci.* 42 (3):97-100; p. 355, footnote 37 and p. 454, reference 110, Rose should read June; p. 398, couplet 1a on line 2 should read 40-43.5% SL or line 3 on p. 402 should read 41-43.5; p. 413, vertebrae of *R. serrata* should be 39 based on Regan 1917, not 29 based on Prince 1907.

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*Digestion of Brown Algae and the
Distribution of Nutrients in the
Purple Sea Urchin
Strongylocentrotus Purpuratus
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DIGESTION OF BROWN ALGAE AND THE DISTRIBUTION OF NUTRIENTS IN THE PURPLE SEA URCHIN *STRONGYLOCENTROTUS PURPURATUS**

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Abstract—1. The purple sea urchin *Strongylocentrotus purpuratus* digests the brown algae *Macrocystis pyrifera* and *Egregia laevigata* with high efficiency, averaging 80 per cent digested for the former and 62 per cent for the latter. The brown algae *Petalonia fascia* and *Haliidrys dioica* are not the usual diet of this animal and are digested with lower efficiencies, 50 and 44 per cent respectively.

2. When digestive efficiencies during continual feeding are compared with those after a single feeding, there appears to be little difference between them.

3. *Macrocystis* labeled with C^{14} was fed to *S. purpuratus* and the time of appearance and distribution of C^{14} were subsequently examined. Within a few hours the plasma of the perivisceral fluid becomes radioactive with a soluble product of digestion which proved to be mannitol, a sugar alcohol which comprises 30 per cent of the alga's dry weight (ash-free). Peaks of radioactivity in the plasma appear as often as radioactive meals are offered to the urchin. Over longer periods the C^{14} is concentrated chiefly in the first and second circuits of the intestine, but incorporation of C^{14} into the gonads occurs much more slowly.

4. The red and white coelomocytes of the perivisceral fluid become radioactive later than the plasma. A high specific activity is reached and maintained in the red coelomocytes hours after the radioactive meal. The number of red coelomocytes in the perivisceral fluid fluctuates, suggesting that these cells may be migrating into and out of the perivisceral fluid.

5. A chemical test for glycogen shows that the red coelomocytes are rich in this polysaccharide in well-fed urchins.

6. Injection of radioactive red coelomocytes into the perivisceral fluid of a non-radioactive urchin results in a distribution of the radioactivity into the tissues of the animal.

7. Evidence is presented of hitherto unknown connections of the hemal system between the gonads and intestines. These connections are filled with red coelomocytes.

8. It is suggested that the hemal system may represent a true circulatory system in the sea urchin *S. purpuratus* and that the red coelomocytes distribute products of digestion throughout the body by this system.

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INTRODUCTION

THE digestion of algae by the purple sea urchin *S. purpuratus* has been the subject of several investigations (Lasker & Giese, 1954; Lasker & Boolootian, 1960; Farmanfarmaian & Phillips, 1962). Work has also been done on the digestion of algal polysaccharides by extracts of *S. purpuratus* gut (Lasker & Giese, 1954; Eppley & Lasker, 1959; Farmanfarmaian & Phillips, 1962) demonstrating that the urchin gut and its bacterial flora have enzymes capable of degrading and depolymerizing the polysaccharides starch, algin, agar, and iridophycin (a galactan chief cell-wall constituent of the red alga *Iridophycus flaccidum*).

The chief algal foods of *S. purpuratus* off Southern California are the brown algae *Macrocystis pyrifera* and *Egregia laevis*. Laboratory tests have shown that the urchin has a high degree of preference for *Macrocystis*; and entire beds of this alga are known to be depleted by this animal (Leighton, personal communication). However, very little information is available on the efficiency with which *S. purpuratus* can digest an algal meal. It was the purpose of this study to determine the percent digestion of brown algae by the sea urchin and to learn further details on the distribution of nutrients in this animal during and after digestion of such algae.

MATERIALS AND METHODS

Two types of experiments were performed to determine the percent of brown algae digested by *S. purpuratus*. In the first experiment, an urchin was provided with an abundant food supply and allowed to feed continually. In the second, on a meal of a known quantity of brown algae was provided and consumed during the first day with no more food given for the duration of the experiment. In some instances, however, 2 full days of feeding were permitted. All urchins were starved for 3 weeks prior to the experiments, until no appreciable solid material could be recovered from the intestines of the control animals. Only the algal fronds were used as food in these experiments.

Individual sea urchins were kept in perforated polyethylene containers wrapped with fine-mesh gauze and submerged in running sea water. The containers were oriented so that fecal pellets would fall to the non-perforated bottom of the container and be recovered. These pellets were collected daily in every experiment. Percent digestion of brown algae by *S. purpuratus* was calculated as follows:

Per cent digested =

$$\frac{(\text{dry weight of algae eaten} - \text{dry weight of feces and gut contents}) \times 100}{\text{dry weight of algae eaten}}$$

Some experiments involved the feeding of C^{14} (carbon-14) labeled-*Macrocystis* and the determination of C^{14} activity in the tissues of sea urchins. The sensitive (± 0.2 per cent) vibrating-reed electrometer (Nuclear Chicago Corporation) was used to measure C^{14} activity as $C^{14}O_2$ after wet combustion of tissues to carbon dioxide (CO_2). A complete discussion of this technique is given by Tolbert (1956).

A strip of *M. pyrifera* frond, 2 cm × 10 cm, was soaked for 3 days under a fluorescent light in 65 ml sea water at 13°C containing approximately 20 μ c of NaHC¹⁴O₃. The relative distribution of radioactivity with respect to the chemical composition of the alga is shown in the analysis by Vaughan (1959) which is discussed in detail later. After several rinses in sea water the alga was fed to *S. purpuratus*. The perivisceral fluid of the urchin can be divided into the plasma (containing dissolved substances) and the cellular components, red and white coelomocytes. Perivisceral fluid (2.7 ml) was removed from the coelomic cavity at intervals with a 5 ml syringe and 0.3 ml 5% sodium hydrosulfite added as an anticoagulant. The cells were centrifuged at 3200 rev/min in a 3 ml Bauer and Schenck tube which effected a sharp separation between the red and white coelomocytes because of the higher density of the former. The volumes of the two cell fractions were recorded, and each fraction was removed with capillary tubes. These were frozen for subsequent C¹⁴ analysis. Perivisceral fluid loss appears to be made up by absorption of sea water by the urchin, as evidenced by recovery of original wet weight when the animal is reimmersed in sea water.

Organic components of the perivisceral fluid were isolated by ion-exchange and subsequently analyzed by paper chromatography. The ion-exchange resins, Zeo-Karb 225 and De-Acidite E (Permutit Co., Inc., New York), were used for the separation of amino acid, organic acid, and sugar fractions using the method of Boolootian (1957).

Two solvents were used to detect mannitol with paper chromatography; *n*-butanol-acetic acid-water (4:1:5 by volume) and ethyl acetate-acetic acid-water (3:1:3 by volume). This sugar alcohol was revealed by spraying the papers with a solution of 40 mg brom-cresol purple dissolved in 100 ml of 95% ethanol containing 100 mg of boric acid and 7.5 ml of 17% aqueous borax solution. Mannitol appears as a yellow spot on a blue background (Block *et al.*, 1958).

Other sugars were revealed in trace quantities by these and other chromatographic solvents. The positions of the sugars, except mannitol, were revealed by dipping the dried chromatograms through a solution of saturated silver nitrate in acetone after which the acetone was evaporated. Dark brown to black spots appear on a background which changes from yellow to brown. The background was controlled by immersing the paper in 2 N ammonia. Whatman No. 1 filter paper (46 × 57 cm) was used throughout.

Total glycogen was analyzed by the method of Good *et al.* (1933) with the extraction procedure conducted at 2.4°C.

RESULTS AND DISCUSSION

Percent digestion of brown algae

Table 1 is a summary of the experiments in which the brown alga *Macrocystis pyrifera* was used as food. It is interesting to note that regardless of whether the animal is fed continually or only an initial, limited meal, the percent of food digested is approximately the same, averaging 81 per cent (range 64–93 per cent for seventeen animals).

No.	Sex	Wet wt (g)	Condition of experiment	Condition of algae	Duration (days)	Total dry wt of algae eaten (g)	Dry wt of gut contents and feces (g)	Digestibility coefficient (%)
1	♀	Apx 50	Fed daily	Live	15	2.2600	0.2337 F 0.2214 G 0.4551	80
2	♀	Apx 50	Fed daily	Live	15	2.2300	0.2135 F 0.2020 G 0.4155	81
3	♂	Apx 30	Fed daily	Live	15	2.2500	0.2458 F 0.1274 G 0.3732	83
4	♂	82.2	Fed daily	Dried	15	1.8849	0.3157 F 0.0748 G 0.3905	79
5	♀	122.9	Fed daily	Dried	10	0.6173	0.0440 F 0.0575 G 0.1015	84
6	♀	71.5	Fed daily	Dried	19	1.6280	0.1980 F 0.0 G 0.1980	88
7	♀	75.6	Fed daily	Dried	18	1.7475	0.1722 F 0.1442 G 0.3164	82
8	♀	44.7	Fed daily	Dried	9	0.5313	0.0355 F 0.0 G 0.0355	93
9	*	Apx 50	Fed only once	Live	15	0.2200	0.0 F 0.0403 G 0.0403	82
10	*	Apx 50	Fed only once	Live	15	0.1100	0.0246 F 0.0093 G 0.0339	64

TABLE 1 (cont.)—DIGESTIBILITY COEFFICIENTS OF *Strongylocentrotus purpuratus* FED THE BROWN ALGA *Macrocystis pyrifera*

No.	Sex	Wet wt (g)	Condition of experiment	Condition of algae	Duration (days)	Total dry wt of algae eaten (g)	Dry wt of gut contents and feces (g)	Digestibility coefficient (%)
11	♀	Apx 50	Fed only once	Live	15	0.3100	0.0886 F 0.0019 G	71
							0.0905	
12	♀	Apx 50	Fed only once	Live	15	0.2400	0.0083 F 0.0407 G	80
							0.0490	
13	♂	32.6	Fed only once	Dried	15	0.1490	0.0360 F 0.0 G	76
							0.0360	
14	*	51.9	Fed only once	Dried	13	0.1083	0.0093 F 0.0 G	91
							0.0093	
15	*	42.9	Fed only once	Dried	16	0.1604	0.0422 F 0.0 G	72
							0.0422	
16	♂	27.3	Fed only once	Dried	15	0.1474	0.0267 F 0.0 G	82
							0.0267	
17	♂	40.4	Fed only once	Dried	15	0.1394	0.0360 F 0.0 G	74
							0.0360	
								$\bar{X} = 80.1$
								S.D. = 7.3

* Sex not determined.
F = feces; G = gut contents; S.D. = standard deviation.

When sea urchins are fed other species of brown algae, e.g. *Egregia*, *Halidrys*, or *Petalonia*, the degree of digestion appears to be considerably lower. The average digestibility coefficient for fourteen urchins fed *Egregia* was 62 per cent (range 48–82 per cent for fourteen animals [Table 2]). The tests using *Petalonia* and *Halidrys* as food showed markedly lower coefficients (Table 3), averaging 50 and 45 per cent respectively.

TABLE 2.—DIGESTIBILITY COEFFICIENTS OF *Strongylocentrotus purpuratus* FED THE BROWN ALGA *Egrecia laevigata*

No.	Sex	Wet wt (g)	Condition of experiment	Duration (days)	Total dry wt of algae eaten (g)	Dry wt of gut contents and feces (g)	Digestibility coefficient (%)
1	♀	58.9	Fed once	11	0.08	0.0364 F 0.0 G	55
2	*	42.2	Fed once	14	0.12	0.0364 0.0365 F 0.0 G	70
3	*	19.3	Fed once	14	0.13	0.0365 0.0650 F 0.0043 G	47
4	♀	*	Fed once for 24 hr	10	0.14	0.0693 0.0483 F 0.0066 G	61
5	♀	*	Fed once for 24 hr	10	0.14	0.0549 0.0444 F 0.0021 G	66
6	♀	*	Fed for 48 hr then no food	10	0.66	0.0465 0.2986 F 0.0175 G	52
7	♀	*	Fed for 48 hr then no food	10	0.33	0.3161 0.1066 F 0.0139 G	63
8	♂	42.8	Fed daily	11	0.37	0.1205 0.0159 F 0.1586 G	53
9	*	69.4	Fed daily	14	1.15	0.1745 0.1404 F 0.0982 G	79
10	♂	32.2	Fed daily	14	1.11	0.2386 0.0828 F 0.1282 G 0.2110	82

TABLE 2 (cont.)—DIGESTIBILITY COEFFICIENTS OF *Strongylocentrotus purpuratus* FED THE BROWN ALGA *Egregia laevigata*

No.	Sex	Wet wt (g)	Condition of experiment	Duration (days)	Total dry wt of algae eaten (g)	Dry wt of gut contents and feces (g)	Digestibility coefficient (%)
11	♂	40.6	Fed daily	14	1.10	0.1268 F 0.1140 G	78
12	♂	*	Fed daily	10	0.69	0.2408 0.2504 F 0.0157 G	61
13	♀	*	Fed daily	10	1.04	0.2661 0.4278 F 0.0396 G	55
14	♂	*	Fed daily	10	1.17	0.4674 0.5278 F 0.0826 G 0.6104	48
							X = 62.1 S.D. = 10.8

* Sex or weight not determined.
F = feces; G = gut contents; S.D. = standard deviation.

In previous experiments we have noted that *S. purpuratus* produced fecal pellets continuously with continuous feeding. It seemed likely, therefore, that the urchins, when feeding continuously, might be wasting much of the organic material available to them since some of the algae remained in the gut for a much shorter period of time than when the animal was fed a single meal. Our present results show that, on the contrary, per cent digestion is always as high or higher in continuously fed animals than in those fed only one meal. Fig. 1 illustrates the fluctuations in fecal production in relation to the intake of food. As feeding increases or decreases so does fecal production. However, the quantitative relation between food ingested and feces remains approximately the same throughout.

The high degree of digestibility of *Macrocystis pyrifera* can best be explained after consideration of its chemical composition. Vaughan's (1959) data for the chemical analysis of this alga are summarized in Table 4. The value for protein and free amino acids is based on a nitrogen content of 2 per cent $\times 6.25$ (Clendenning, personal communication). The two major fractions are alginic acid and the monosaccharide, mannitol. Eppley & Lasker (1959) have shown that algin

is rapidly depolymerized and degraded by the sea urchin's gut enzymes, accounting for rapid digestion by the urchin. Mannitol, which is 30 per cent of the alga's ash-free dry weight, appears in the perivisceral fluid soon after ingestion. This was shown by analyzing the perivisceral fluid for soluble components after an urchin had fed on *Macrocystis*. Mannitol was shown to be present in the perivisceral fluid as determined by paper chromatography.

TABLE 3—DIGESTIBILITY COEFFICIENTS OF *Strongylocentrotus purpuratus* FED THE BROWN ALGAE *Halidrys dioica* AND *Petalonia fascia*

No.	Sex	Wet wt (g)	Condition of experiment	Duration (days)	Total dry wt of algae eaten (g)	Dry wt of gut contents and feces (g)	Digestibility coefficient (%)
1	♀	44.6	Fed <i>Halidrys</i> once	11	0.1663	0.0056 F 0.0834 G	47
						0.0890	
2	♀	48.5	Fed <i>Halidrys</i> daily	11	0.6997	0.0967 F 0.3008 G	43
						0.3975	
3	♀	65.4	Fed <i>Petalonia</i> daily	12	0.6072	0.1629 F 0.1277 G	52
						0.2906	
4	♂	67.3	Fed <i>Petalonia</i> daily	12	0.6001	0.1740 F 0.1183 G	49
						0.2923	
							$\bar{X} = 51$

F = feces; G = gut contents.

Appearance of nutrients in the perivisceral fluid of S. purpuratus after digestion of brown algae

In a recent paper, Farmanfarmanian & Phillips (1962) described the rapid influx of radioactive materials into the perivisceral fluid of *S. purpuratus* after a meal of the red alga, *Iridophycus flaccidum* (syn. *Irیدهae*) which had been labeled with C¹⁴. We performed similar experiments independently with urchins feeding on the brown alga *Macrocystis pyrifera*. Because of the possibility that phagocytosis or cellular translocation might be an important mechanism in digestion by the sea urchin, we also studied the role of the coelomocytes. (For a description of these cells see Boolootian & Giese, 1958, and Boolootian, 1962.)

Two short-term experiments were run to ascertain the rate at which dissolved materials enter the perivisceral fluid of an urchin. The results are shown in Fig. 2.

Radioactive dissolved substances appeared at the first sampling (1 and 3 hr following ingestion) and continued to increase. A primary peak of activity appeared between 4 and 6 hr in both cases. During this time no activity could be detected in either the red coelomocytes (elaeocytes) or the white coelomocytes.

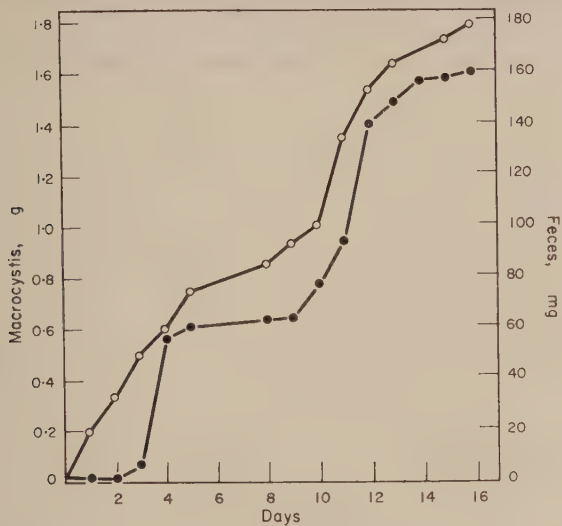


FIG. 1. *Macrocystis* consumption and fecal production of a sea urchin. Note different ordinate scales. ○—○, *Macrocystis*; ●—●, feces.

Because the urchin's cellular elements were not radioactive within the 8 hr period of these experiments, it was important to determine which organic components of the plasma contributed to the radioactivity.

TABLE 4—COMPARISON OF THE PERCENTAGE COMPOSITION OF ASH-FREE AND DRY *Macrocystis pyrifera* WITH THE PERCENT OF TOTAL C¹⁴ ACTIVITY IN THE ALGA'S COMPOUNDS AFTER 6 HR PHOTOSYNTHESIS (VAUGHAN, 1959)

Compound	Approximate % comp.	% C ¹⁴
Ether solubles	2.8	2.2
Mannitol	29.8	36.0
Laminarin and fucoidin	4.8	2.6
Alginic acid	38.2	41.1
Cellulose	1.1	8.8
Protein and free amino acids	12.0*	9.3

* Protein content based on nitrogen value of 2 per cent × 6.25 (Clendenning, personal communication).

After 7 hr of digestion of labeled *Macrocystis*, the perivisceral fluid was removed from an urchin and fractionated into amino acid, organic acid and sugar fractions by ion-exchange (Booolootian, 1957). Of the total dissolved 14,000 disintegrations/min (dpm) which was present in the perivisceral fluid after digestion of the radioactive alga, 12,420 dpm was recovered after ion-exchange. Of this, only 644 dpm (5.2 per cent) was in the amino acid fraction and 11,776 dpm (94.8 per cent) was found in the sugar fraction. No activity was found in the organic acid fraction.

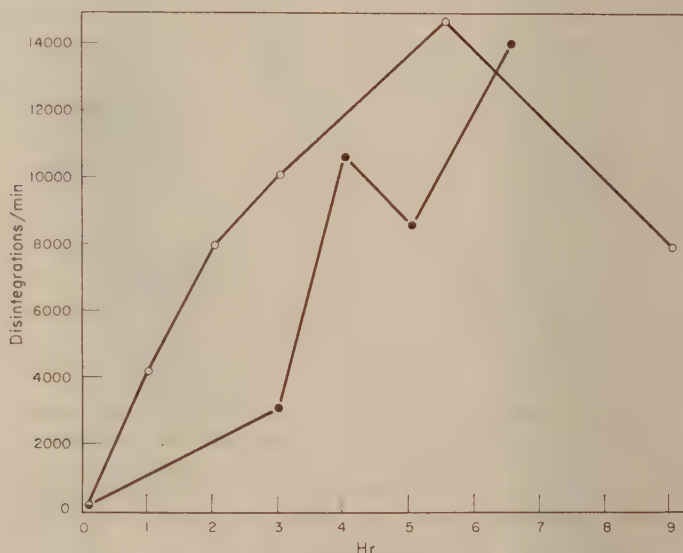


FIG. 2. Appearance of C^{14} -labeled substances in the plasma after a meal of radioactive algae. ○—○, Animal No. 1; ●—●, Animal No. 2.

In Fig. 3 the radioactivity of the perivisceral fluid of one urchin is shown as it was distributed between plasma, red coelomocytes and the white coelomocytes. This animal was not tested until 8 hr following ingestion of radioactive *Macrocystis*. The high level of radioactivity at 8 hr is not maintained, but falls off rapidly. These results are similar to those of Farmanfarmaian & Phillips (1962) using red algae as food. However, when the food is *Macrocystis* it is not uncommon to have a second peak of activity appear later as more dissolved substances appear in the body fluid. Whether this is due to mobilization from tissues of the animal or to further digestion of the ingested algae has not been determined. In one instance the second peak appeared more than 90 hr following algal ingestion. This peak coincides with an increase in the radioactivity of the red coelomocytes (Fig. 3). The white coelomocytes become radioactive more slowly than the red coelomocytes. Fig. 4 shows the increase in red and white cell volumes with time.

It is also evident that as the red coelomocytes in the perivisceral fluid increase in numbers (as indicated by volume measurements), there is a corresponding increase in their total radioactivity following a meal of radioactive algae. An apparent correlation exists between the radioactivity of the red coelomocytes, the packed cell volume and the increase in activity of the plasma. The specific activity of the red coelomocytes remained high (Table 5) between 96 and 144 hr, although during this interval the radioactivity of the plasma decreased greatly and the number of red coelomocytes diminished.

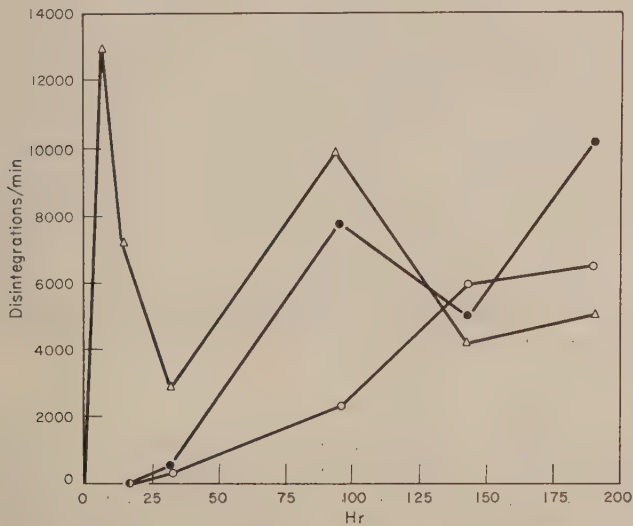


FIG. 3. Radioactivity of perivisceral fluid constituents after a meal of C^{14} -labeled *Macrocystis pyrifera*. All volumes corrected per unit volume of perivisceral fluid. Δ — Δ , plasma; $\bullet$ — $\bullet$, red coelomocytes; $\circ$ — $\circ$, white coelomocytes.

Our interpretation of these results is that the red coelomocytes may be actively migrating into and out of the perivisceral fluid and that over very long periods of time both specific activity and numbers of red coelomocytes increase. This suggests that red coelomocytes are picking up radioactive compounds from a site other than the plasma because the plasma has lost most of its radioactivity before any significant activity increase appears in the red coelomocytes. Therefore the red coelomocytes may be transporting nutrients.

The appearance of radioactivity in the white coelomocyte fraction presents a different picture. Uptake of C^{14} by the white coelomocytes is much slower than by the red coelomocytes, and although there is an increase in white cell number, specific activity levels fall off over long periods of time (Table 5).

Repeated feedings of radioactive algae resulted in cyclic peaks of activity appearing in the plasma (Fig. 5). This shows rapid absorption by the gut of

readily soluble algal compounds. Paper chromatographic analysis showed that these peaks were due chiefly to mannitol. Farmanfarmaian & Phillips (1962) showed a similar phenomenon in urchins feeding on red algae except that the chief compound found in the perivisceral fluid was galactose.

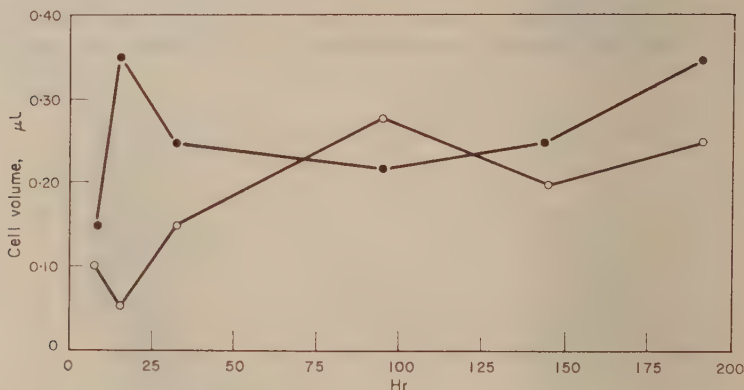


FIG. 4. Cell volume changes with time during repeated sampling of perivisceral fluid. Each point represents the cell volume in 2.6 ml of perivisceral fluid. ●—●, red coelomocytes; ○—○, white coelomocytes.

Distribution of radioactivity in the tissues

Figure 6 is a histogram showing the percent distribution of radioactivity in *S. purpuratus* 22 hr after a meal of uniformly labeled *Macrocystis*. The major concentration of radioactivity was in the cells of the first and second circuits of the alimentary canal. Incorporation of C^{14} occurred uniformly in all five ovaries. We have shown by biopsy that C^{14} can be detected in these organs as early as 8 hr after feeding.

Function of the red coelomocytes

The role of the red coelomocytes has never been completely elucidated, although Jacobson & Millott (1953) have determined that they are active agents in melanogenesis. Griffiths (1892) and Awerinzew (1911) believed that the red coelomocytes were important in oxygen transport, but Tyler (1939) showed that the pigment echinochrome does not participate in respiration. Cuénot (1891) suggested, without experimental evidence, that these cells were a possible store of food material which the cells had taken from the intestine.

Red coelomocytes are abundant in the tissues of the alimentary canal. The greatest numbers are found in the first and second circuit of the alimentary tract. Fig. 7(A) is a photograph of a segment of the intestinal epithelium depicting the red coelomocytes *in situ*. A histochemical test (Okamoto *et al.*, 1948) to show localization of glucose was applied to urchin gut tissue. The red coelomocytes were strongly positive and stained deep brown (Fig. 7(B)) while the epithelium

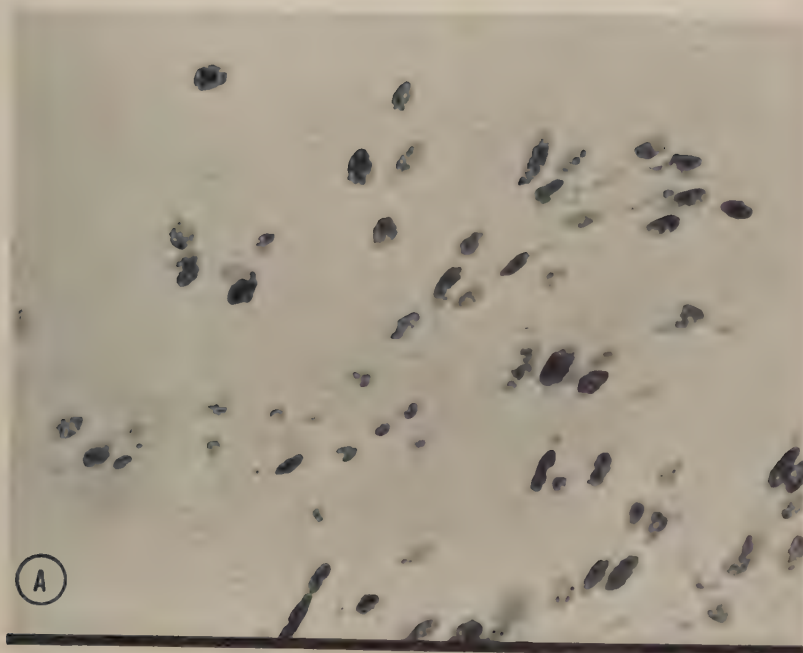


FIG. 7. Photomicrographs of the intestinal epithelium. (B) Red coelomocytes are strongly stained brown, as compared with (A) where the red coelomocytes are shown *in situ* without staining. $\times 384$.

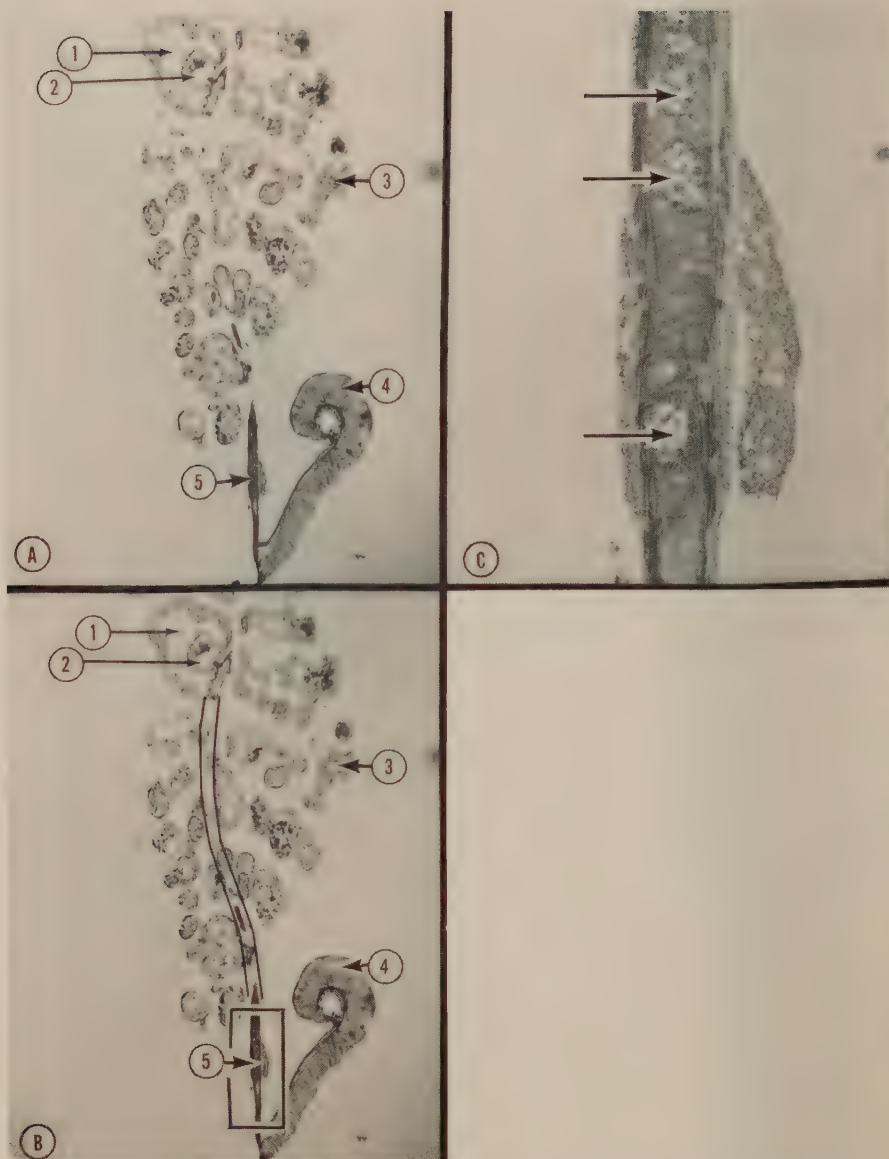


FIG. 8. Photomicrograph of a hemal connection between the second circuit of the intestine and the gonad. One of a series of serial sections. The superimposed lines (B) indicate full extent of the connection not shown in the photograph. (A) hemal connective without reconstruction; (B) reconstruction; (C) enlargement of inset (B) showing lumen of hemal connective and red coelomocytes *in situ*. (1) gonoduct; (2) hemal canal; (3) acini; (4) intestinal epithelium of second circuit; (5) hemal connective.

did not. Red cells in well-fed urchins proved to be rich in glycogen (approximately 0.15 per cent of the dry weight: range 0.10–0.22 per cent for determinations) whereas white cells have none. We starved three urchins for 45 days and could not detect glycogen in their red coelomocytes after this period of time. When these same animals were subsequently fed for 2 weeks on *Macrocystis* the glycogen level became normal (0.11 per cent). These data, when considered together, suggest that the red coelomocytes are a site for glycogen synthesis and storage.

TABLE 5—VOLUME CHANGE AND SPECIFIC ACTIVITY OF RED AND WHITE COELOMOCYTES AFTER A MEAL OF RADIOACTIVE ALGAE

Red Coelomocyte Fraction			
Time (hr)	Red coelomocyte packed volume in 2.7 ml p.f.	DPM/cells in 25 ml p.f.	Specific activity DPM/0.25 ml red coelomocytes
8	0.010	0	0
16	0.005	0	0
32	0.015	580	386
96	0.028	7709	2760
144	0.020	4982	2500
192	0.025	10138	4060
White Coelomocyte Fraction			
Time (hr)	White coelomocyte packed volume in 2.7 ml p.f.	DPM/cells in 25 ml p.f.	Specific activity DPM/0.25 ml white coelomocytes
8	0.015	0	0
16	0.035	0	0
32	0.025	440	176
96	0.022	2265	1030
144	0.025	5952	2390
192	0.035	6460	1845

DPM = disintegrations per minute; p.f. = perivisceral fluid

An experiment was designed to test the hypothesis that red coelomocytes can distribute nutrients to other tissues and the plasma. Radioactive red coelomocytes were obtained from the perivisceral fluid of an urchin fed uniformly labeled *Macrocystis*. These cells were washed seven times in sea water and yielded a packed volume of 0.226 ml with a total activity of 6286 dpm. The cells were suspended in 0.5 ml sea water and injected into the perivisceral cavity of a well-fed, but non-radioactive urchin. Two hours after this treatment the animal was sacrificed and its tissues analyzed for radioactivity. It was found that the intestine became most radioactive (1009 dpm) of the tissues, acquiring 16 per cent of the red coelomocyte activity. The plasma and gonads became slightly radioactive with 313 (5 per cent) and 67 dpm (1 per cent) of the red coelomocyte activity respectively.

Red cells appear to migrate into the body fluid as shown by the increase in volume of red cells during periodic sampling of perivisceral fluid. Radioactive red cells, when injected into the perivisceral fluid of an urchin, either lose their radioactivity to the tissues of the animal or migrate into it. Our interpretation of these experiments is that the red coelomocytes, and perhaps the white cells to a lesser extent, may be involved in nutrient transport. The recently discovered hemal connections containing red cells between intestine and gonads lend further support to this hypothesis.

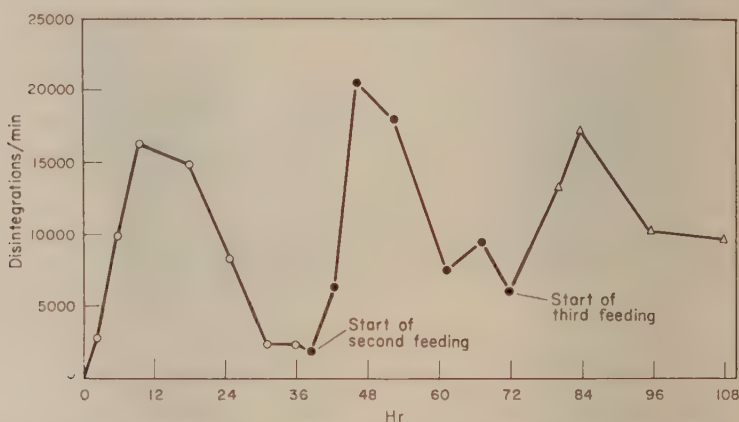


FIG. 5. Cyclic appearance of C^{14} -labeled compounds in plasma following three consecutive but separate feedings of *Macrocystis pyrifera*. ○—○, specific activity of alga = 140,962 dpm/mg; ●—●, 286,362 dpm/mg; △—△, 186,643 dpm/mg.

Probable role of the hemal system

It is interesting to note that Nakano & Monroy (1957) found that unfertilized sea urchin eggs failed to incorporate any appreciable quantities of radioactive organic compounds *in vitro*. They found that incorporation was achieved when radioactive substances were injected into the perivisceral cavity and the eggs remained *in situ*. This indicates that a vital mechanism and/or some particular anatomical arrangement is needed for utilization of organic substances into the tissues of the urchin which cannot be explained by simple diffusion or osmosis from the plasma.

In echinoids, the hemal system is found penetrating the major organs as a series of ill-defined sinuses, lacunae and vessels (Hyman, 1955). Heretofore only a single connection to each of the five gonads has been seen (Hyman, 1955; Grassé, 1948). A recent experiment by Farmanfarmanian & Phillips (1962) showed that the severance of these known hemal connections did not impair the uptake of radioactivity by the gonads. On the basis of this experiment they concluded that nutrients must enter the gonads via routes other than the hemal system.

A study of the micro-anatomy of the hemal system (Campbell & Boolootian, to be published) has revealed that, in addition to the single connection previously described, there are many additional ones (twenty or more for each gonad) between the dorsal marginal sinus of the second circuit of the intestine and the gonads. Fig. 8 shows one of these connections. Red coelomocytes are invariably found in the tubules of this system lending support to the hypothesis that this system may be analogous to a true circulatory system.

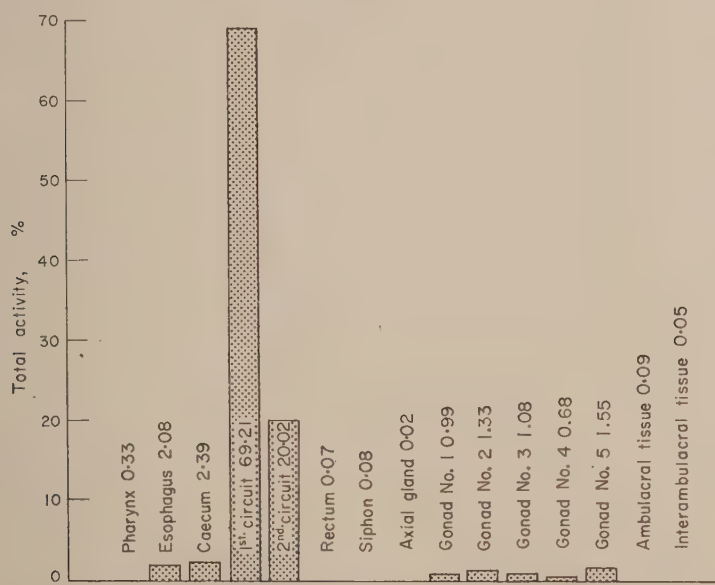


FIG. 6. Distribution of radioactivity in the tissues of *S. purpuratus* 22 hr after a meal of uniformly labeled *Macrocystis*.

Digestive physiology of the sea urchin

The results of this study clearly show that the sea urchin, *S. purpuratus*, can digest the brown alga *Macrocyctis pyrifera* with a high efficiency averaging 81 per cent. Mannitol, the chief storage product of the alga, is absorbed rapidly and appears in quantity in the plasma soon after a meal of *Macrocyctis* has begun. Efficiency of absorption of soluble nutrients is known to be very high (over 90 per cent) and complete as shown by injection of glucose into the perivisceral cavity (Lasker & Giese, 1954) and by incorporation of easily labeled substances found in the red alga *Iridophycus flaccidum* after digestion (Farmanfarmaian & Phillips, 1962).

Digestion of other brown algae is less efficient than digestion of *Macrocyctis*. This is probably due to a different chemical composition of the other three species tested, *Egrecia*, *Petalonia* and *Halidrys*. Because no information of the chemical

composition of these species is available, it is not yet possible to correlate digestibility with their chemical composition.

Farmanfarmaian & Phillips (1962) describe digestive efficiency in terms of loss of C^{14} -labeled substances from the red alga *Iridophycus flaccidum* after ingestion by *S. purpuratus*. However, Bean & Hassid (1955) have shown that 10 hr of C^{14} -labeling by photosynthesis of this alga does not result in uniform labeling. Instead the major cell wall constituent of this alga, iridophycin, making up 40 per cent of the dry weight of the plant (Hassid, 1936) has 2.7 per cent of the incorporated C^{14} only. Although easily labeled substances may be expected to enter the perivisceral fluid rapidly, caution must be exercised in interpretation of digestion of the entire alga throughout long experimental periods if the detection of C^{14} alone is used as the criterion.

The role of the coelomocytes has not been entirely elucidated. Our results show (Fig. 3) that both red and white coelomocytes become labeled after the urchin has digested a meal of C^{14} -*Macrocystis*, but that the red cells are usually higher in specific activity than the white cells. The red cells contain glycogen whereas the white cells do not. In most cases the red cells have an increasing specific activity while the specific activity of the plasma is decreasing.

The present experiments and those of a number of workers (Weese, 1926; Lasker & Giese, 1954; Bennett & Giese, 1955; Eppley & Lasker, 1959; Lasker & Boolootian, 1960; Farmanfarmaian & Phillips, 1962) collectively provide an overall picture of the physiology of digestion in the purple sea urchin.

This herbivorous animal seems remarkably well adapted to a diet of brown and red algae. It contains the enzymes to digest the complex algal polysaccharides and proteins. The efficiency with which it can digest algae and absorb the products of digestion is high. It seems likely that the ubiquitous hemal system is a unique circulatory system having numerous connections to the gonads and provides pathways for migration of red coelomocytes to all parts of the animal's tissues. The red coelomocytes may distribute acquired nutrients to these tissues. The plasma is the probable recipient of the immediately soluble substances obtained from algal meals which are secreted into the perivisceral fluid by an active gut epithelium. Numerous organic compounds, e.g. amino acids, sugars, organic acids and peptides, are always present in low concentration in the plasma (Boolootian, 1961). Thus the coelomocytes have available to them at all times a reserve of nutrients, which they can probably absorb and later release to the tissues. We have not been able to exclude the possibility that urchin tissues receive nutrients directly from the plasma. Yet it is difficult to imagine the large gonads (particularly during the peak of the reproductive cycle) receiving nutrients by absorption from the plasma because of the great distance over which diffusion or absorption would have to take place. It seems more likely that the hemal system provides the avenue for the deposition of nutrients at sites within the gonads.

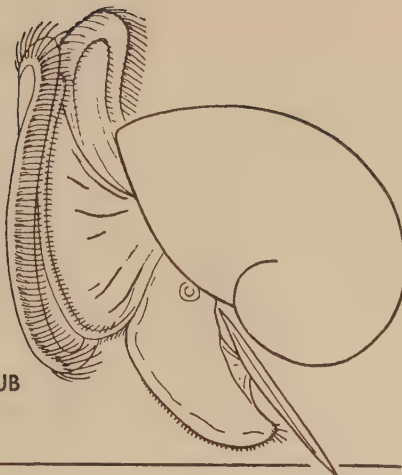
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ORDER, Suborder, **DIVISION**, *Subdivision*, SECTION,

SUPERFAMILY, FAMILY, Subfamily, *Genus*, (*Subgenus*).

New Taxa

A Note on the Synonymy of *Tellina subtrigona* SOWERBY, 1866 (Mollusca: Bivalvia)

BY

KENNETH J. BOSS

U. S. Fish and Wildlife Service, Washington, D. C.

(Plate 27, Figures 1, 1 a)

IN 1866, SOWERBY first described *Tellina subtrigona* in volume 17 of REEVE's *Conchologia Iconica*; the type figure is figure 9, plate 3 of *Tellina*; no locality datum was given. Later, in 1868, in the same monograph, he again described a species with the name *Tellina subtrigona* (plate 44, figure 259). After he discovered his error, he corrected the latter to *Tellina subangulata* in the index; *T. subangulata* is synonymous with the Indo-Pacific species, *T. juvenilis* HANLEY.

Recently, KEEN (1958) has suggested the probable identity of *Tellina erythronotus* PILSBRY & LOWE with *T. subtrigona* SOWERBY, 1866. HERTLEIN & STRONG (1949) in their remarks under *T. erythronotus*, did not mention *T. subtrigona*, but have listed the names of a number of species which are synonymous with or closely related to *T. subtrigona*. In 1852, C. B. ADAMS described *T. puella* from the Pacific coast of Panama; this name was unfortunately preoccupied by *T. puella* HANLEY 1846. SALISBURY (1934) recognized *T. puella* ADAMS as a junior homonym and renamed it *T. puellula*. TURNER (1956) selected and figured the lectotype of *T. puella* ADAMS. KEEN (1958) considered *T. puellula* as valid but mentioned that it was very close to *T. erythronotus*. OLSSON (1961) recognized that *T. puella* ADAMS and its substitute name, *T. puellula* SALISBURY, were synonymous with *T. erythronotus*.

Presently, we are able to include *Tellina subtrigona* SOWERBY, 1866 in this synonymy, and this name will replace *T. erythronotus*. An examination of the type material has indicated the identity of the following: *Tellina*

subtrigona SOWERBY, 1866; *T. puella* C. B. ADAMS; *T. puellula* SALISBURY; and *T. erythronotus* PILSBRY & LOWE. Plate 27, figures 1 and 1 a illustrate the holotype of *T. subtrigona* SOWERBY, 1866 and the following in synonymy of the species:

Tellina subtrigona SOWERBY, 1866 [in] REEVE, *Conchologia Iconica*, vol. 17, *Tellina*, pl. 3, fig. 9 (type locality unknown; holotype, BMNH, no catalog number; 22 mm in length and 13 mm in height), *non* SOWERBY, 1868.

Tellina puella C. B. ADAMS, 1852, *Ann. and Lyceum Nat. Hist. New York*, 5: 507 and 546 (reprint pages 283 and 322); TURNER, 1956, *Occ. Pap. Moll., Harv. University*, 2 (20): 77, pl. 19, figs. 13, 14 (type locality Panama [Pacific coast]; lectotype, selected by TURNER, 1956, MCZ 186305; 22 mm in length, 13 mm in height and 7 mm in diameter), *non* HANLEY, 1846.

Tellina erythronotus PILSBRY & LOWE, 1932, *Proc. Acad. Nat. Sci. Philadelphia*, 84: 94, pl. 12, fig. 7 (type locality, Panama, east of the city; holotype, ANSP 11510; 19.5 mm in length, 10.7 mm in height, and 5 mm in diameter).

Tellina puellula SALISBURY, 1934, *Proc. Mal. Soc. London*, 21 (2): 86 (new name for *T. puella* C. B. ADAMS, 1852, *non* HANLEY, 1846).

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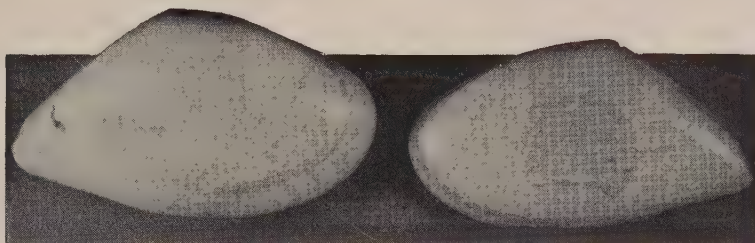


Figure 1

Figure 1 a

Figure 1, 1a: The holotype of
Tellina subtrigona SOWERBY, 1866 (about x 2.3).

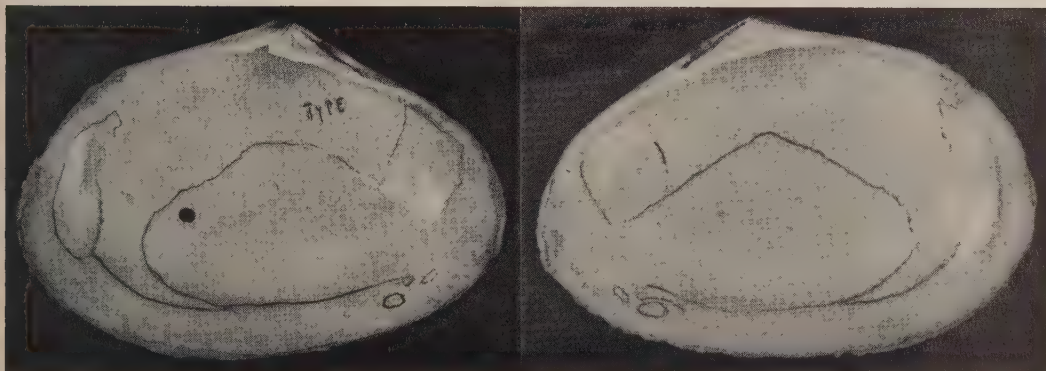


Figure 2

Figure 2 a

Figures 2 and 2 a: The holotype of
Scrobicularia viridotincta CARPENTER in the type
collection of the British Museum (Natural History) ; Reg.
No. 19621115. Figure 2: Right valve internal; Figure 2 a:
Left valve internal (both about x 1.4).

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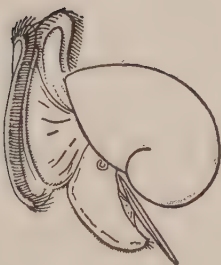
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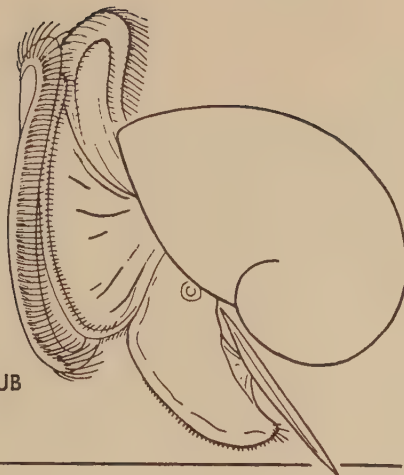
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New Taxa

The Status of *Scrobicularia viridotincta* CARPENTER

(Mollusca: Bivalvia)

BY

KENNETH J. BOSS

U. S. Fish and Wildlife Service, Washington, D. C.

(Plate 27, Figures 2, 2 a)

IN 1856, P. P. CARPENTER described a new species of bivalved mollusk as '*? Scrobicularia virido-tincta*.' The type specimen was collected by Mr. T. Bridges in the Bay of Panama and was later deposited in the collection of Mr. Hugh Cuming. Presently the holotype is in the type collection of the British Museum (Natural History).

Notwithstanding the incomplete description and the lack, until recently (see PALMER, 1963), of an illustration of the holotype, there have been virtually no questions concerning the identity of *Scrobicularia viridotincta*. DALL (1900) created a new section, *Scrobiculina*, of the subgenus *Arcopagia* with *Scrobicularia viridotincta* CARPENTER as type, and nearly all modern authors have followed this scheme in systematic treatments of the TELLINIDAE. DALL considered that *Tellina* (*Peronaeoderma*) *ochracea* CARPENTER, 1864 also belonged to the section *Scrobiculina* and, further, that the species *T. ochracea* and *S. viridotincta* were distinguished from each other by the umbo, the former species being ochraceous or somewhat yellow-orange while the latter was greenish. However, an examination of the type of *Scrobicularia viridotincta* CARPENTER shows this species to possess macomid characteristics, and the following figures, description and remarks attempt to clarify the definition of *S. viridotincta* CARPENTER and *Scrobiculina* DALL.

DESCRIPTION OF

Scrobicularia viridotincta CARPENTER

Original description: ? *S. testa*. ? *S. productae* similis sed latiore, ovali tenuiore, magis planata, antice haud producta, alba; umbonibus viriditinctis.

Redescription of holotype (Plate 27, figures 2, 2 a): Shell 51.8 mm in length and 35.1 mm in height; diameter 16.0 mm; distance from anterior margin to umbonal axis 28.5 mm, distance from anterior margin to anterior margin extension of the pallial sinus, 12.8 mm. Shell white, ovate, slightly inequivalve with the right valve larger and of greater convexity, slightly inequilateral and with a slight posterior flexure to the right, inflated anteriorly and somewhat compressed posteriorly. Umbones situated behind the middle, blunt, with conspicuous dark green coloration, slightly elevated and somewhat inflated with a deep umbonal cavity beneath. Anterior margin rather broadly and smoothly rounded; ventral margin slightly arcuate and convex; posterior margin but slightly produced, rather narrowly rounded. Sculpture consists of closely spaced weak concentric lirae; no true radial sculpture evident. Right valve with a posterior ridge, left valve with a corresponding furrow. Ligament brown in color, sunken and subtended by a strong cartilagenous element or resilium, shorter than the ligament

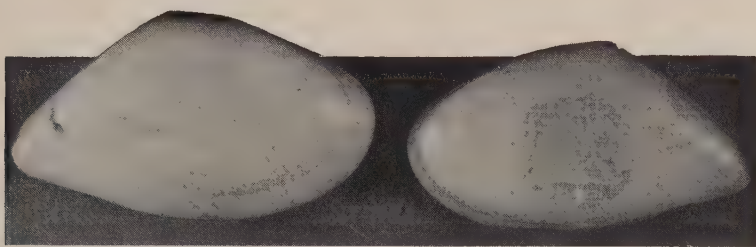


Figure 1

Figure 1 a

Figure 1, 1a: The holotype of
Tellina subtrigona SOWERBY, 1866 (about x 2.3).

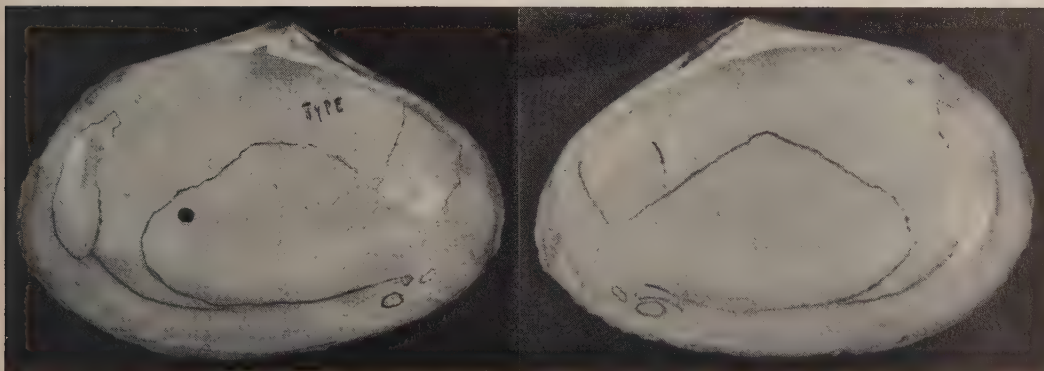


Figure 2

Figure 2 a

Figures 2 and 2 a: The holotype of
Scrobicularia viridotincta CARPENTER in the type
collection of the British Museum (Natural History); Reg.
No. 19621115. Figure 2: Right valve internal; Figure 2 a:
Left valve internal (both about x 1.4).

der. Cardinal complex in the left valve consists of a narrowed anterior bifid tooth with more or less lobes and of an elongate posterior laminate tooth which is obsolete and adpressed to the calcareous element by the ligament; no lateral teeth present. Cardinal complex in the right valve consists of a short posterior bifid tooth with subequal lobes and of an anterior laminate tooth; the single anterior laminate cardinal tooth is broken off part of the hinge plate which supports it; no lateral teeth present. Anterior adductor muscle scar elongate and narrow, weakly lunate; posterior adductor scar transverse, subquadrate, nearly rhomboid. Pallial sinus rising behind the apex beneath the umbo but not higher than the almost extension of the posterior adductor muscle scar; the sinus descending in an arcuation toward the dorsal line, paralleling it for a distance and then becoming confluent with it well in front of the umbonal axis, about the beginning of the hinge plate. Cruciform muscle scars subequal, the anterior scar subquadrate and the posterior scar more nearly rounded; the terminus of the pallial line anterior and near to the posterior cruciform muscle scar.

Remarks: The most important characteristic to be considered in the holotype is the complete absence of lateral teeth. Although a portion of the shell is broken in the vicinity of the anterior lateral hinge plate in the right valve, enough structure is evident to indicate that no lateral tooth was present. It is only possible for the broken anterior portion to have contained the most distal part of the anterior laminate cardinal tooth. The lack of any lateral teeth, the thickness, coloration and dullness of the shell, and the deep placement of the ligament indicate that this species is a member of the genus *Psammotreta* of the subfamily Macominae. By no stretch of definitions could it be considered a *Tellina* or a *Semele*. OLSSON (1961) elevated *Psammotreta* to the generic level, while HERTLEIN & STRONG (1949) considered it a genus. The latter authors listed two species in this taxon: *Macoma (Psammotreta) aurora* (HANLEY, 1844) and *(P.) pacis* (PILSBRY & LOWE, 1932). OLSSON listed *P. aurora* (HANLEY, 1844), *P. dombei* (HANLEY, 1844), *P. andis* (HANLEY, 1844), *P. asthenodon* (PILSBRY & LOWE, 1932), and *P. gubernacula* [sic] (HANLEY, 1844), under which *M. (P.) pacis* (PILSBRY & LOWE) is treated as a synonym. KEEN (1962) maintained *Psammotreta* DALL as the generic level and indicated that *Psammotreta (P.) pacis* (PILSBRY & LOWE) is not synonymous with *P. (P.) gubernaculum* (HANLEY, 1844), an interpretation which is followed here. Of all the species in *Psammotreta*, it appears that *Scrobicularia viridotincta* CARPENTER is senior synonym of *Psammotreta pacis* (PILSBRY & LOWE).

The discovery of the correct identity of *viridotincta* CARPENTER upsets the traditional usage of *Scrobiculina*. DALL (1900) established *Scrobiculina* as well as *Psam-*

motreta, but *Scrobicularia* has page priority over *Psammotreta*. However, Article 24 (a) of the International Code of Zoological Nomenclature insures that if more than one name for a single taxon has been published simultaneously, relative priority and the choice of one of the names to represent the taxon may be determined by the first person to point out the synonymy. Further, Recommendation 24 A of the Code instructs the first reviser to select the name 'that will best ensure stability and universality of nomenclature.' In this particular case, I hereby select *Psammotreta* as the name to be preserved and *Scrobicularia* is assigned the status of a junior synonym.

DALL's concept of *Scrobicularia viridotincta* CARPENTER does not actually represent a valid species. An examination of the material of *Tellina ochracea* and the so-called '*viridotincta* CARPENTER' of DALL in the British Museum (Natural History), the Museum of Comparative Zoology, and the United States National Museum indicates that *T. ochracea* is a polymorphic species in which green and yellow colored specimens are identical morphologically and represent nothing more than color variations.

The closest relative to *Tellina ochracea* is the western Atlantic species, *T. laevigata* LINNAEUS, 1758, which also possesses a wide range of color variation. Probably *T. ochracea* was derived from *T. laevigata* after the closure of the Central American isthmus in the Pliocene. *Tellina laevigata* appears to be more heavily shelled and more tumid; its color is generally red and often disposed in rays, although colorless individuals are frequently encountered in populations.

A problem arises in subgenerically placing *Tellina ochracea*. *Laciolina* IREDALE, 1937, based on *T. quoyi* SOWERBY, suitably fills the need. In addition to *T. quoyi*, *T. chloroleuca* LAMARCK, 1818 also represents *Laciolina* in the Indo-Pacific, and both are very similar to *T. laevigata* and *T. ochracea*. Their common ancestry becomes immediately evident when samples of each species are compared.

In summary, the status of *Scrobicularia viridotincta* CARPENTER is discussed. An examination of the holotype shows this species to be synonymous with *Psammotreta pacis* PILSBRY & LOWE. The sectional or subgeneric name *Scrobiculina* DALL, based upon *Scrobicularia viridotincta* CARPENTER, is herein designated (interpreted) as a junior synonym of *Psammotreta*. DALL's *S. viridotincta* 'CARPENTER' is synonymous with the species *Tellina ochracea* CARPENTER. *Laciolina* IREDALE is an available subgenus into which are placed *T. ochracea* CARPENTER, *T. laevigata* LINNAEUS, *T. quoyi* SOWERBY and *T. chloroleuca* LAMARCK.

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For permission to study and photograph specimens in the British Museum (Natural History), the author is

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UNIONIDAE OF RED CEDAR RIVER, MICHIGAN

BY KENNETH J. BOSS

U. S. Fish and Wildlife Service, Washington, D. C.

The major objectives of this note are to document more fully the distribution of 14 species of unionids in the Red Cedar River, to indicate some areas of pollution, and to provide a record of faunal changes since the report of van der Schalie (1940).

The Red Cedar River is a tributary stream of the Grand River in western Michigan. Its main channel is nearly 50 miles in length and its total drainage area, including its three main tributaries, is approximately 355 square miles. The bottom types are variable, but the lower portions of the stream are gravel or rock while the upper are predominantly sand. The minimum discharge flow (July, 1931) was 3 cubic feet per second while the maximum (April, 1946) was 5,510 cubic feet per second; therefore, the depth at any one station in the river varies according to the amount of precipitation and evaporation. The river is slightly alkaline and highly buffered and in some areas the oxygen content is above 90% saturation (Brehmer, 1956).

During the fall of 1958, a series of collecting stations along the river was sampled for the unionid fauna. Five general areas may be delimited:

1. At East Lansing, Ingham County. Here 4 stations were made, all upstream from the local sewage treatment facilities. The bottom type was predominantly gravel.
2. At Okemos, Ingham County. This area included five stations in the vicinity of Okemos; the substrates were gravel, sand and mud.
3. At Williamston, Ingham County. Three stations were made in this area; bottom types included gravel, sand and mud with some local concentrations of silt.
4. At Webberville, Ingham County. The three stations here were made in sand and gravel substrates.
5. At Fowlerville, Livingston County. Soft clay and mud substrates were typical of the two stations in this area.

The following is a list of the species with numbers, designating the areas in which specimens were collected. Most of the specific names are modeled after Clarke and Berg (1959).

Elliptio dilatatus (Rafinesque), 1, 2, 3, 4.

Fusconaia flava (Rafinesque), 1, 2, 3, 5.

Pleurobema cordatum (Rafinesque), 1, 2, 3.

Anodonta grandis (Say), 1, 2, 3, 4, 5.

Lasmigona compressa (Lea), 4, 5.

Lasmigona costata (Rafinesque), 1, 2, 3.

Anodontoides ferussacianus (Lea), 1, 2, 3, 4, 5.

Strophitus undulatus (Say), 1, 2, 3, 4, 5.

Alasmidonta calceolus (Lea), 2.

Alasmidonta marginata (Say), 2, 3.

Villosa iris (Lea), 2.

Lampsilis radiata siliquoidea (Barnes), 1, 3, 4, 5.

Lampsilis ovata ventricosa (Barnes), 1, 2, 3, 4.

Actinonaias ellipsiformis (Lea), 1, 2.

The most common species was *Elliptio dilatatus* while *Fusconaia flava*, *Anodonta grandis*, *Strophitus undulatus* and *Lampsilis ovata ventricosa* were moderately common and the most widely distributed. *Villosa iris*, *Actinonaias ellipsiformis*, *Lasmigona compressa* and *Alasmidonta calceolus* were rare. When a comparison of these observations with those of van der Schalie (1940) is made, a decrease in the abundance of *Villosa iris*, *Actinonaias ellipsiformis* and *Alasmidonta calceolus* is evident while an increase in the abundance of *Anodonta grandis*, *Lasmigona costata* and *Alasmidonta marginata* is obvious. The stream is entirely devoid of unios immediately downstream from Fowlerville and East Lansing; industrial and sewage effluents have rendered the conditions unsuitable for the maintenance of the unio fauna in these areas.

The author is indebted to Dr. T. W. Porter for his guidance and help in the field; to Dr. H. van der Schalie, who kindly advised on the identification of some species; and to Mr. R. I. Johnson, who checked some aspects of the nomenclature.

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NOTES ON A HYBRID TELLINA (TELLINIDAE)

BY KENNETH J. BOSS

U.S. Fish and Wildlife Service, Washington, D.C.

The occurrence of hybridization between species or genera of mollusks has been reported infrequently in the literature. A general review of possible cases has been given by Pelseneer (1920). Data on natural and experimental hybridization between species of the land snail *Cerion* (Bartsch, 1920 and 1955; Mayr and Rosen, 1956) suggest that the phenomenon may occur with some frequency. In the Bivalvia, experimental hybridization has been studied and obtained between species of *Ostrea* and *Crassostrea* (Seno and Hori [in] Miyazaki, 1939; Davis, 1950), *Pholas* [*Zirfaea* + *Barnea*] (Pelseneer, 1920), *Venus* [*Mercenaria*] (Chestnut, Fahy, and Porter, 1957) and *Pinctada* (Matsui, 1958). In many cases the experimental hybrids are subject to high, if not complete, mortality. Some evidence has been marshalled to show that certain species or subspecies of North American unionids hybridize (Clarke and Berg, 1959). The example given herein records a case of hybridization between two closely related species of the genus *Tellina*.

The hybrid specimen and the specimens of the parental species (Plate 3, figs. 1, 2, 3) were collected in Bermuda by Mr. Russell H. Jensen of Bloomfield, New Jersey, in September 1963. He kindly sent them to the author for study. The two species involved, *Tellina magna* Spengler, 1789 and *T. laevigata* Linnaeus, 1758, are largely sympatric and closely related but possess a number of qualitative as well as quantitative species characteristics. The populations sampled by Mr. Jensen came from Tucker's Bay, Harrington Sound. The average depth of water was 6 feet and the individuals were living 12 inches below the surface of a fine sand substrate. The sample consisted of 2 specimens of *magna*, 7 of *laevigata* and the unique hybrid.

Conchologically, *magna* may be separated from *laevigata* by its elongate-elliptical shape, its lateral compression, its generally whitish coloration, which may be suffused centrally with pink, orange, and red, and by its obsolete posterior lateral tooth in the right valve. In addition, the ligament of *magna* is somewhat

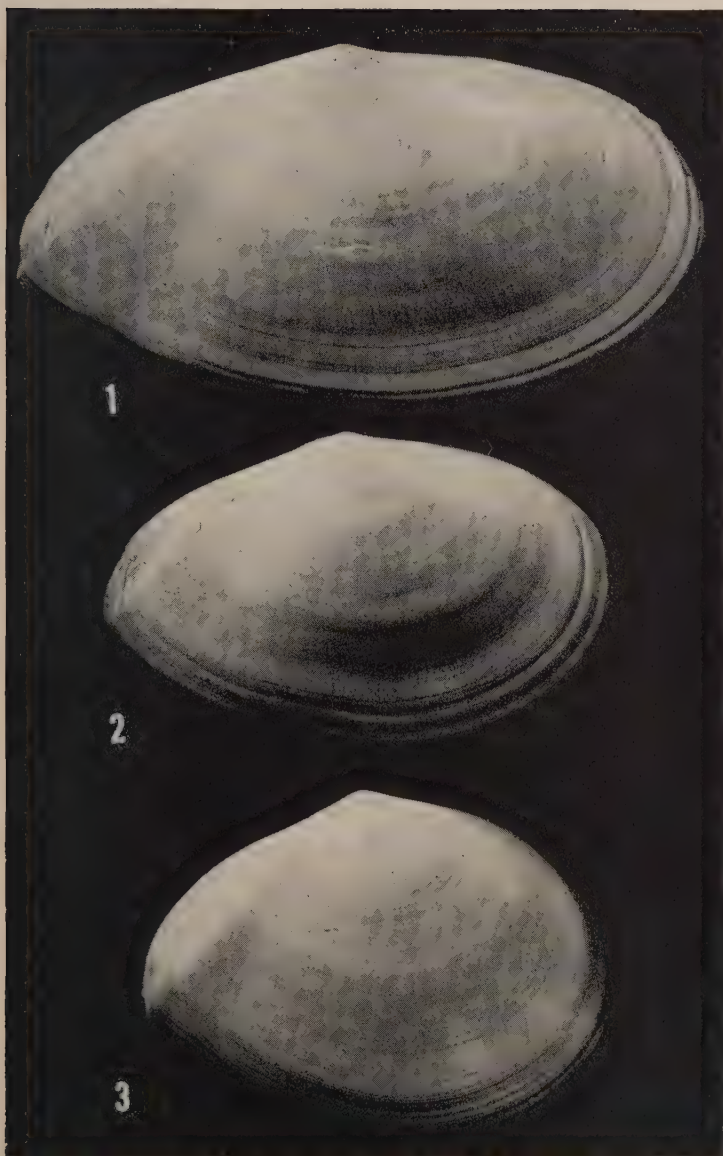
sunken and the margins of the valve in this area are sharp; whereas in *laevigata* the ligament is more protuberant and its margins are smooth and beveled. The periphery of the shell in *laevigata* is typically orange-yellow. The convexities of the valves and the outlines of the shells may be quantified by measurements of lengths, widths, heights, and ratios thereof.

Based on measurements of series of each species, including the samples from Bermuda, the mean length-height ratio for *magna* is 1.8 with a range from 1.6 to 2.1, for *laevigata* 1.3 with a range from 1.2 to 1.4; the mean length-width ratio for *magna* is 5.7 with a range from 5.4 to 6.3, for *laevigata* 3.5 with a range from 2.9 to 3.8. These ratios show that *magna* is proportionally more elongate and more compressed than *laevigata*.

The hybrid specimen is intermediate in its qualitative conchological characteristics. It has an internal suffusion of colors which is unlike that of *magna* but like that of *laevigata* in as much as the suffusion is not concentrated centrally, but peripherally. On the other hand, the umbo shows the typical external concentration of orange-red coloration which is generally found in specimens of *magna*. The right posterior lateral tooth is weakly developed but is more definitive than the obsolete tooth in *magna* and less definitive than the strong tooth possessed by *laevigata*. Since the characteristics of the dispensation of coloration alone seem to be unsatisfactory criteria upon which to conclude that a specimen is a hybrid, the shape of the shell was also considered.

The measurements of the hybrid are: length 78.7 mm.; height 51.3 mm.; width 20.5 mm. The length-height ratio is 1.53 and the length-width ratio is 3.8. The former lies clearly out of the range of these ratios for either parental species and the latter coincides with the greatest extreme of *laevigata*. In any case, the ratios of the hybrid are well separated from the means of the parental species and the shape of the shell is intermediate in its dimensions.

Consideration of the occurrence of a hybrid between *laevigata* and *magna* lends credence to their inclusion in the subgenus *Laciolina* Iredale, a procedure followed in the author's forthcoming monograph of the Tellininae. It also calls attention to some inherent weaknesses in the establishment of subgenera in the Tellinidae on lateral dentition alone. As practiced in other



External views of the right valves. Fig. 1 *Tellina magna* Spengler. Fig. 2. Hybrid specimen. Fig. 3. *T. laevigata* Linnaeus. (All about $0.85\times$).

taxonomic groups, the hybrid may be referred to as *Tellina magna* x *laevigata*.

The discovery of an adult hybrid between two closely related and relatively abundant western Atlantic tellens not only adds another record of hybridization among bivalves, but opens a promising avenue for experimental research. The stability of *magna* and *laevigata* indicates that the hybrid is probably infertile for there has not been any introgressive merging of populations of the parental species.

The author wishes to acknowledge the suggestions given by Drs. J. Rosewater and W. J. Clench, who critically read the manuscript.

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New species of *Tellina* from the Western Atlantic

By KENNETH J. BOSS
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During the course of a revisionary study of the Tellininae of the Western Atlantic, six new species were encountered. As the publication of the complete monograph of this group will be long in preparation and as these new species may be of interest to workers, it was deemed advisable to publish descriptions of these species without delay.

The rather specialized vocabulary utilized in the description of each species is explained in Plate 54, figs. 1 and 2. Abbreviations used consistently in the text include: MCZ, Museum of Comparative Zoology, Harvard University; BMNH, British Museum (Natural History), London; USNM, United States National Museum, Washington, D.C.; ANSP, Academy of Natural Sciences of Philadelphia; IMBPR, Institute of Marine Biology of Puerto Rico; and CNM, Canadian National Museum, Ottawa.

***Tellina* (*Merisca*) *alerta*, new species** Plate 55, figs. 1-2

Description. Shell extending to 8.3 mm. (about 1/3 inch) in length and to 6.5 mm. (about 1/4 inch) in height, elongate-subtrigonal, subsolid to thin, a little tumid with the left valve more convex and with a sharp flexure to the right posteriorly. Umbos central and pointed. Anterior margin smoothly rounded; ventral margin gently convex and rising in a concave basal arcuation posteriorly; anterior dorsal margin

straight and gently inclined; posterior margin short, parallel with the dorso-ventral axis and forming a blunt truncation. Sculpture consisting of regularly spaced, raised lamellae (about 10-12 per millimeter) separated by sulci. Ligament light brown and slightly protuberant. Calcareous portion of the ligament poorly developed. In the left valve, the cardinal complex consists of an anterior subdeltoid bifid tooth with subequal lobes and of a posterior extremely elongate laminate tooth; distal anterior and posterior lateral teeth present, protruding and weak. In the right valve, the cardinal complex consists of a posterior thickened bifid tooth with subequal lobes and of an anterior subdeltoid laminate tooth; distal anterior and posterior lateral teeth present, elongate, strong, upcurled and socketed. Adductor muscle scars well impressed. Anterior adductor scar elongate, pointed above and rounded below; posterior adductor scar subquadrate. Pallial sinus equal in opposite valves, rising gently behind, widely separated from the anterior adductor scar and forming a short confluence posteriorly. Periostracum dull reddish-brown; the external surface of the valves eroded in the umbonal region and the remainder a dull white.

length	height	width	
8.3 mm.	6.5 mm.	3.0 mm.	Paratype of <i>alerta</i>
8.3	6.0	2.8	Holotype of <i>alerta</i>

Types. The holotype of *Tellina (Merisca) alerta* is in the British Museum (Natural History), no. 79.10.15.171.2; type locality, 32°45' S; 50°39' W, about 15 miles SE of Rio Grande do Sul, Brasil, in 48 fathoms; specimen collected by R. W. Coppinger on the HMS *Alert*.

Remarks. *Tellina alerta* is most closely allied to *Tellina aequistriata* Say. The shape of the shell, the concentric sculpture and the configuration of the lateral teeth of the right valve serve to indicate the close relationship between these species. The pallial sinus is the most important character used to distinguish these species. In *aequistriata*, the sinus falls to and is confluent with the pallial line at or very near the base of the anterior adductor muscle scar while in *alerta* it is widely separated from the anterior adductor scar and the confluence of the sinus, and the pallial line is short. *Tellina alerta* possesses a distinct reddish-brown periostracum which differs from the

white periostracum of *aequistriata*, and the lateral compression of the valves appears to be greater in *alerta*.

Range and specimens examined. The species is known only from the type locality.

***Tellina (Angulus) paramera*, new species**

Plate 55, figs. 3 and 8

Description. Shell extending to 14.5 mm. (about 5/8 inch) in length and to 12.5 mm. (about 1/2 inch) in height, ovate, sub-solid to solid, moderately inflated with both valves of more or less equal convexity and with or without a slight posterior flexure to the right. Umbos posterior to the middle, somewhat elevated, inflated and blunt. Anterior margin broadly rounded; ventral margin convex and rising slightly posteriorly; anterior dorsal margin straight and gently sloping; posterior dorsal margin rather steeply inclined, short and slightly convex; posterior margin short and forming an irregular blunt truncation. Concentric sculpture consisting of closely set, raised ridges (about 8-10 per millimeter) separated by shallow sulci; radial sculpture consisting of poorly developed, evenly spaced lirations which more or less cover the disc. Ligament reddish brown, poorly developed, not protuberant and sunken in an elongate and narrow escutcheon; lunule poorly defined, shallow and broad. Calcareous element of the ligament moderately developed and resting on a flattened hinge plate; no true nymphaal callosities. In the left valve, the cardinal complex consists of an anterior deltoid bifid tooth with subequal lobes and of a posterior elongate thickened laminate tooth; no true lateral teeth present. In the right valve, the cardinal complex consists of a posterior, elongate slightly skewed bifid tooth with subequal lobes and of an anterior thickened, subdeltoid laminate tooth; anterior lateral tooth large, strong, thickened and proximal to the cardinal complex; posterior lateral absent or obsolete, consisting of a weak enlargement in the distal terminus of the hinge plate with an indented socket above. Adductor muscle scars not strongly impressed. Anterior adductor elongate and lunate; posterior scar transversely quadrate. Pallial sinus usually equal in opposite valves, rising abruptly behind, forming a rounded apex above and descending gently to the

Plate 54

Diagrammatic representation of the shell morphology of a generalized *Tellina*.

Fig. 1. Internal view of a right valve.

1. Cardinal complex with the single anterior laminate cardinal tooth and the bifid cardinal tooth.
2. Ligament.
3. Nymphal callosity.
4. Posterior lateral tooth.
5. Posterior adductor muscle scar.
6. Cruciform muscle scars.
7. Pallial sinus.
8. Pallial line.
9. Interlinear scar.
10. Anterior adductor scar.
11. Pedal retractor scars.
12. Anterior lateral tooth.

Fig. 2. External view of a left valve.

1. Umbo.
2. Anterior dorsal margin.
3. Oblique sulcus or scissulation.
4. Anterior margin.
5. Disc.
6. Ventral margin.
7. Concentric sculpture.
8. Posterior margin.
9. Posterior slope.
10. Posterior dorsal margin.

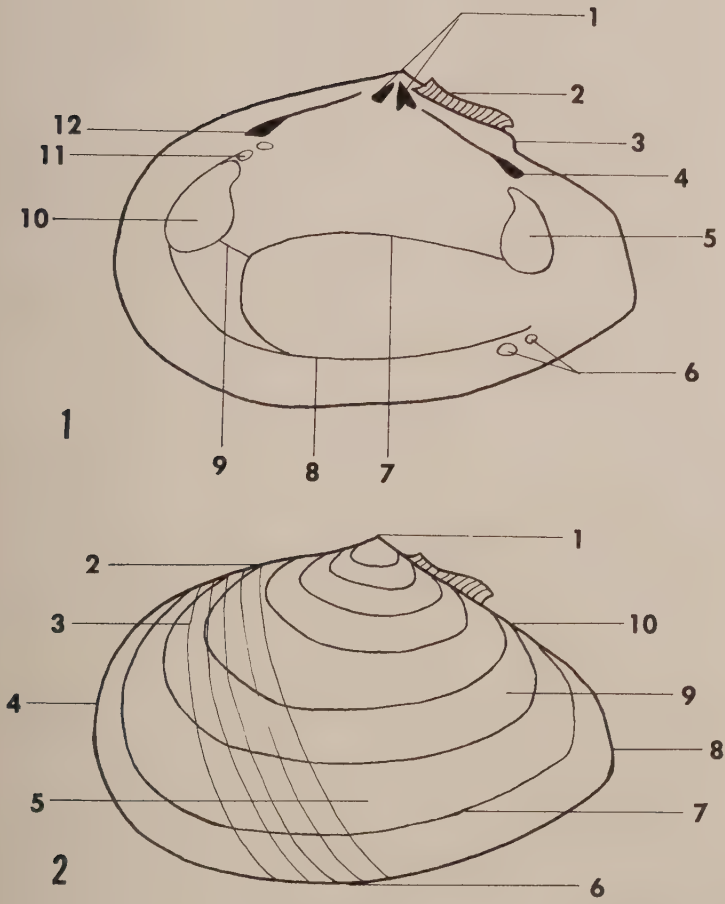


Plate 54

pallial line below; confluence entire. The pallial sinus generally does not coalesce with the anterior adductor scar but unites with the pallial line just beneath the anterior adductor scar. Externally, the shell is dull white; internally, shining, not highly polished and tending to become chalky; the internal surface often possesses radial vermiculations which reflect the external radial sculpture.

length	height	width	
12.5 mm.	10.0 mm.	5.2 mm.	Holotype of <i>paramera</i>
14.5	12.5	6.5	'Florida Keys'
10.3	8.4	4.3	Off Miami, Florida
9.2	7.2	—	Off Miami, Florida
6.2	4.5	—	Off Miami, Florida

Types. The holotype of *Tellina (Angulus) paramera* is in the Museum of Comparative Zoology, no. 242904; type locality, off Miami Beach, Florida, in 8 1/2 fathoms.

Remarks. This species is easily confused with *Tellina mera* Say, its nearest ally in the fauna of the Western Atlantic. The similarity in shape and color combined with the morphological similarities of the hinge line serve to indicate the close relationship of *mera* and *paramera*. In the latter, however, the shell is noticeably thicker and heavier and, in addition, the posterior margin forms a diagnostic blunt truncation. The configuration of the pallial sinus distinguishes *paramera* from its relatives. In *mera*, the sinus though extending toward the anterior adductor muscle scar, is separated from it; the sinus then parallels the pallial line and unites with it posteriorly, forming a short confluence. In *paramera*, the pallial sinus is closely aligned to the anterior adductor muscle scar, if not contiguous with it, and the confluence of the pallial sinus with the pallial line is virtually complete, extending the entire ventral length of the pallial line.

Tellina paramera occurs from the shore line to depths of fifty fathoms. As specimens are relatively rare and the species has remained unrecognized to date, it is postulated that an off-shore habitat in moderate depths is preferred. An analog of *Tellina paramera* is not recognized from the Eastern Pacific.

Range. The species occurs from Bermuda, through the Ba-

hama Islands and off the coast of southeastern Florida to the Barbados, British West Indies.

Specimens examined. FLORIDA: off Miami Beach, in 6-30 fathoms; off Bear's Cut, Miami, in 18-20 fathoms; off Government Cut, in 3-38 fathoms; off Bell Buoy, Miami, in 15-22 fathoms; off Fowey Light, in 22-40 fathoms; Bird Key, Biscayne Bay, in 2-10 feet (all USNM); off American Shoals, in 45 fathoms (MCZ); Key West; Tortugas, in 15 fathoms (both USNM). BERMUDA: Ferry Point, St. George's Island (USNM). BAHAMA ISLANDS: Grand Bahama (USNM); Thompson's Bay, Long Island (MCZ). CUBA: Cape Cajon; Cayo Levisa; Bahia Honda, in 1-12 fathoms (all USNM). HISPANIOLA. SANTO DOMINGO: Puerto Sousa (MCZ). LESSER ANTILLES: off Payne's Bay Church, in 50 fathoms, and Carlisle Bay, in 6 fathoms, Barbados (both USNM).

***Tellina (Angulus) exerythra*, new species**

Plate 55, fig. 7

Tellina (Eurytellina) vespuciana 'd'Orbigny' Dall and Simpson 1901, Bull. U.S. Fish. Comm., **20**(1): 480, non d'Orbigny 1842.

Description. Shell extending to 18.5 mm. (about 3/4 inch) in length and to 11 mm. (about 3/8 inch) in height, subtrigonal, subsolid to solid, inflated with the left valve more convex and with a variously developed posterior flexure to the right. Umbos just posterior to the middle, slightly elevated and pointed. Anterior margin broadly rounded; ventral margin slightly convex and rising in a gentle arcuation posteriorly; anterior dorsal margin elongate and convex; posterior dorsal margin rather steeply inclined and straight; posterior margin short, parallel to the dorso-ventral axis and forming a small truncation. Concentric sculpture consisting of more or less widely and evenly spaced sulci separated by broad, flattened bands; no radial sculpture. Ligament light brown, weak and protuberant. Calcareous portion of the ligament subtended by short and weak nymphal callosities. In the left valve, the cardinal complex consists of an anterior elongate bifid tooth with subequal lobes and of a posterior elongate laminate tooth; no true lateral teeth present. In the right valve, the cardinal complex consists of a posterior, skewed and thickened bifid tooth with subequal

Plate 55

Fig. 1. *Tellina alerta* n. sp., paratype, BMNH; 32°45' S; 50°39' W, off Rio Grande do Sul (right valve internal; 4.5×).

Fig. 2. *Tellina alerta* n. sp., holotype, BMNH; 32°45' S; 50°39' W, off Rio Grande do Sul (left valve external; 4.6×).

Fig. 3. *Tellina paramera* n. sp., holotype, MCZ 242904, off Miami Beach, Florida (right valve external; 2.6×).

Fig. 4. *Tellina probrina* n. sp., holotype, USNM 461905, off Fowey Light, Florida (right valve internal; 2.7×).

Fig. 5. *Tellina euvitrea* n. sp., holotype, USNM 461952, Santa Lucia, Pinar del Rio, Cuba (right valve internal; 2.8×).

Fig. 6. *Tellina diantha* n. sp., holotype, MCZ 239110, Barbados, British West Indies (right valve internal; 2×).

Fig. 7. *Tellina exerythra* n. sp., holotype, MCZ 239220, Boca del Infierno, Bahía de Samaná, Santo Domingo (right valve internal; 2.9×).

Fig. 8. *Tellina paramera* n. sp., holotype, MCZ 242904, off Miami Beach, Florida (right valve internal; 3.4×).

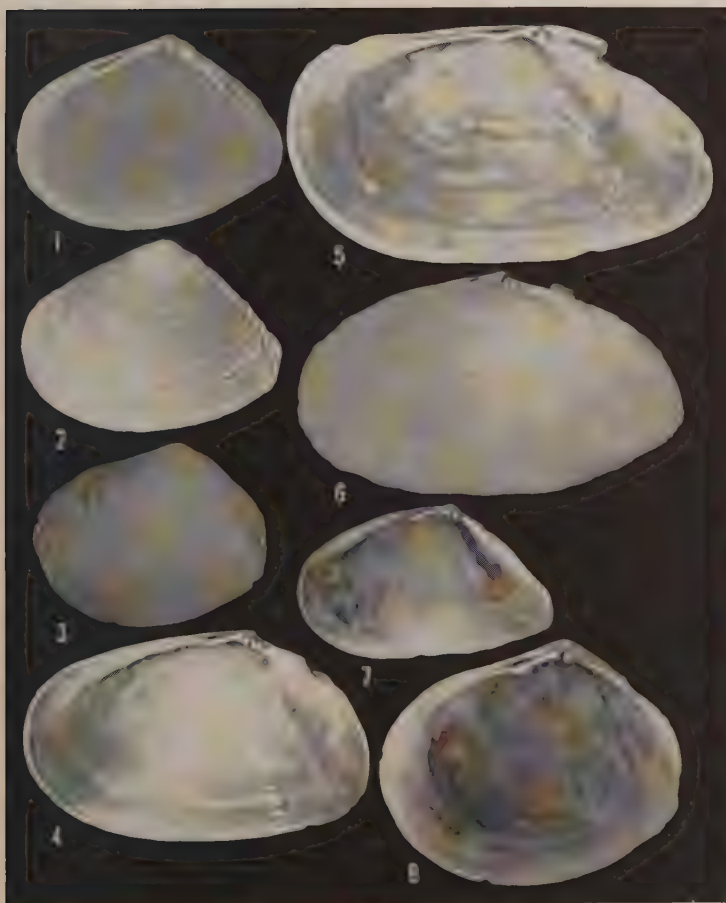


Plate 55

lobes and of an anterior subdeltoid laminate tooth; anterior lateral tooth thickened, upcurled and proximal to the cardinal complex; small distal vestige of the posterior lateral tooth evident. Adductor muscle scars moderately impressed. Anterior adductor scar elongate and rounded below; posterior adductor scar rounded. Pallial sinus more or less equal in both valves, rising gently posteriorly, descending in a concave line, extending nearly to but separated from the anterior adductor muscle scar and falling in a short rounded arcuation to the pallial line. Shell basically ivory white in color with a predominance of red suffusion; the periphery is generally white and variously formed rays of red, white or pink underlie the posterior ridge; external surface shining and sometimes iridescent; internal surface generally highly polished.

length	height	width	
12.0 mm.	7.0 mm.	3.5 mm.	Holotype of <i>exerythra</i>
18.5	11.0	—	West Indies
10.3	6.5	3.0	Mayaguez, Puerto Rico
7.0	4.3	1.9	Bahía de Samaná, Santo Domingo

Types. The holotype of *Tellina (Angulus) exerythra* is in the Museum of Comparative Zoology, no. 239220; type locality, Boca del Infierno, Bahía de Samaná, Santo Domingo, Hispaniola.

Remarks. *Tellina exerythra* appears to occur in considerable numbers off the two easternmost islands of the Greater Antilles. It is most easily confused with and closely related to *T. versicolor* De Kay. In general, *exerythra* is subtrigonal in shape, bright red in color and relatively high in proportion. In this respect it can be contrasted with the elongate elliptical shape and whitish coloration of *versicolor*. The shell of *exerythra* is thicker, heavier and of a greater convexity than that of *versicolor*. The posterior ridges of *exerythra* are rather strongly developed, and there are generally one or two supernumerary ridges separated by weak sulci upon the posterior slope. In contrast, *versicolor* possesses less definitely developed posterior ridges, and extra ridges do not seem to be evident.

In the south Atlantic, *Tellina gibber* v. Ihering, because of its strong shell and the configuration of its pallial sinus, may be related to *exerythra*, but *gibber* lacks the red coloration and possesses a distinctly divided posterior margin with a peculiar and strongly developed posterior sulcus.

Tellina subtrigona Sowerby of the Eastern Pacific is quite similar to *T. exerythra* but the Pacific species attains a greater size.

Range. The species appears to be concentrated in the area of the Greater Antilles exclusive of Cuba. Some specimens have been found at Colon, Panama and others in Brazil.

Specimens examined. GUATEMALA: Livingston (ANSP). BRITISH HONDURAS: Belize (ANSP). JAMAICA: Little Goat Island, Portland Bight (MCZ). HISPANIOLA. HAITI: Aquin; Bizoton (both USNM). SANTO DOMINGO: Monte Cristi (ANSP); Puerto Plata; Bahía de Samaná (both MCZ). PUERTO RICO: Mayaguez; Puerto Real; Ponce (all IMBPR). PANAMA: Colon (MCZ). BRAZIL: (MCZ).

***Tellina* (*Angulus*) *probrina*, new species**

Plate 55, fig. 4

Description. Shell extending to 25 mm. (about one inch) in length and to 14 mm. (about 9/16 inch) in height, elongate to subrectangular in shape, fragile, compressed, with the left valve of slightly greater convexity and with a slight posterior flexure to the right. Umbos posterior to the middle, small and pointed. Anterior margin broadly rounded; ventral margin straight to slightly convex; anterior dorsal margin long and gently sloping; posterior dorsal margin short, slightly concave and slightly inclined; posterior margin long and forming an oblique and blunt truncation. Sculpture consisting of weakly incised and irregularly spaced, concentric sulci; no radial sculpture present. Ligament light brown and protuberant. The calcareous portion of the ligament is subtended by strongly developed and protuberant nymphal callosities in both valves. In the left valve, the cardinal complex consists of a narrow anterior bifid tooth with elongate lobes and of a thin and curved laminate tooth; no true lateral teeth. In the right valve, the cardinal complex consists of a strongly skewed posterior bifid tooth whose posterior lobe is the larger and of an anterior slightly thickened and subdeltoid laminate tooth; anterior lateral proximal, laminate and curved upward; posterior lateral absent or obsolete. Adductor muscle scars moderately

impressed. Anterior adductor muscle scar irregularly shaped, but elongate and rounded below; posterior adductor more or less rounded. Pallial sinus rising very abruptly from the posterior adductor muscle scar to a high point beneath the umbo, then gently descending, rounded anteriorly and arcuately falling to the pallial line. The pallial sinus is well separated from the anterior adductor muscle scar. Shell white to pink or flesh-colored with a variously shaped posterior ray which may be absent in bleached individuals. The periostracum imparts an iridescence to the external surface of the valves, and the internal surface may be shining.

length	height	width	
18.5 mm.	11.0 mm.	—	Holotype of <i>probrina</i>
25.3	14.0	—	Off Freeport, Texas
16.0	9.4	—	Bird Key, Florida
14.2	8.4	2.5 mm.	Off Fowey Light, Florida
11.1	6.5	2.1	Sombrero Key, Florida
8.3	4.8	—	Bird Key, Florida

Types. The holotype of *Tellina (Angulus) probrina* is in the U.S. National Museum, no. 461905; type locality, *Eolis* Station 151, off Fowey Light, Florida, in 55 fathoms.

Remarks. *Tellina probrina* is most easily recognized by its subrectangular shape and its broad, flattened and oblique posterior truncation. Young individuals closely assume the proportions of average adults but very large individuals have the truncation more oblique and the anterior dorsal margin less gently inclined. The vitreous external appearance also identifies this species, but its nearest relative in the Western Atlantic, *Tellina euvitrea*, may be confused with it. However, *euvitrea* has a straight and peculiar anterior dorsal margin, nearly parallel with the ventral margin. In contrast to *probrina*, *euvitrea* is more tumid, much more pointed behind, and with a pallial sinus which does not arise so abruptly from the posterior adductor muscle scar.

Another species with which *Tellina probrina* may be confused is *T. consobrina* d'Orbigny, however, the latter is distinctly allied to the subgenus *Scissula* and its sculpture may be used to distinguish it from *probrina*. In addition, *probrina* is more compressed, higher in proportions, and more strongly and broadly truncate.

Range. This species occurs in depths up to 100 fathoms. It is found in the Straits of Florida off Miami, in the Gulf of Mexico, and in the Caribbean to Tobago.

Specimens examined. FLORIDA: off Government Cut, Miami; off Fowey Light; off Ragged Key; off Bird Key; off Triumph Reef (all USNM); off Sombrero Key (MCZ); off Sand Key; Key West; Dry Tortugas (all USNM). TEXAS: 68 miles SE of Freeport, in 48 fathoms; 80–100 miles S of Port Isabel, in 40 fathoms (both MCZ). BAHAMA ISLANDS: (USNM). LESSER ANTILLES: Grenada (USNM); 2 miles S of Fort George, Scarborough, Tobago, in 36 fathoms (MCZ).

***Tellina (Angulus) euvitrea*, new species**

Plate 55, fig. 5

Tellina (Angulus) vitrea 'd'Orbigny' Dall and Simpson 1901, Bull. U.S. Fish. Comm. **20**(1): 481, non d'Orbigny 1842.

Description. Shell extending to 21 mm. (about 3/4 inch) in length and to 12 mm. (about 7/16 inch) in height, elongate-elliptical, thin, only slightly inflated with the right valve of a greater convexity and with only a slight flexure to the right posteriorly. Umbos just posterior to the middle, opisthogyrous, pointed and not elevated. Anterior margin very broadly rounded; ventral margin straight and with a slight postbasal arcuation: anterior dorsal margin not descending, long, straight and parallel to the ventral margin; posterior dorsal margin variously sloping and short; posterior margin short and poorly defined. Sculpture consisting of weak concentric sulci which are separated by broad bands. Radial sculpture consisting of extremely weak and obscure lirations which are more or less restricted to the peripheral areas. Ligament light brown, strong and protuberant. Calcareous portion of the ligament well developed and subtended by a short nymphal callosity. In the left valve, the cardinal complex consists of an anterior fragile bifid tooth and of a posterior thin and weak laminate tooth; no true lateral teeth present. In the right valve, the cardinal complex consists of a strong posterior bifid tooth with a poorly developed sulcus and a strong anterior and heavy laminate tooth; no true posterior lateral tooth present; anterior lateral proximal to the cardinal complex, rather small and laminate.

Adductor muscle scars generally well impressed. Anterior adductor scar irregularly elongate, smaller than the posterior scar. Pallial sinus equal in opposite valves, pointed above, descending rather steeply, and smoothly arcuate anteriorly. The sinus is deep but is well separated from the anterior adductor muscle scar. Externally the shell is iridescent and banded with white or pink; internally, the shell is usually white.

length	height	width	
21.0 mm.	11.0 mm.	4.5 mm.	Holotype of <i>euvitrea</i>
20.0	11.0	4.0	Bahía de Samaná, Santo Domingo
11.0	6.0	—	Puerto Plata, Santo Domingo

Types. The holotype of *Tellina* (*Angulus*) *euvitrea* is in the U.S. National Museum, no. 461952; type locality, *Barrera Station* 200, Santa Lucia, 15 miles SW of La Esperanza, Pinar del Rio, Cuba, in 2-4 fathoms.

Remarks. This species had actually been recognized by Dall and Simpson in their report on the mollusks of Puerto Rico, and it was at that time called '*Tellina vitrea* d'Orbigny', but the holotype of *vitrea* d'Orbigny is a young individual of *Tellina magna* Spengler. *Tellina euvitrea* is characterized by its periostracum which imparts a vitreous lustre to the external surface of the valves. Its closest relative in the Western Atlantic is *Tellina probrina*, from which *euvitrea* may be separated by a more gently rising pallial sinus, a more pointed posterior end, and by a peculiar anterior dorsal margin which is parallel to the ventral margin. In addition, *Tellina probrina* is compressed whereas *euvitrea* is somewhat inflated. Some individuals of *T. versicolor* may be confused with *euvitrea*, but generally the red coloration and the pallial sinus which is closely aligned to the anterior adductor muscle scar in *versicolor* serve to identify it.

Range. This species appears to be restricted to the Greater Antilles except for Jamaica where it has not been recorded.

Specimens examined. CUBA: Santa Lucia, in 2-4 fathoms; La Esperanza, in 4-6 feet; Bahia Honda, in 1-12 fathoms; Cabanas Harbor, in 3-12 fathoms (all USNM). HISPANIOLA. SANTO DOMINGO: Puerto Plata (MCZ); Bahía de Samaná (USNM).

PUERTO RICO: Aguadilla; mouth of Anasco River, in 40-60 feet (both MCZ); Mayaguez, in 42-60 feet (IMBPR; USNM); off Ponce, in 50 feet (IMBPR).

***Tellina (Angulus) diantha*, new species**

Plate 55, fig. 6

Description. Shell extending to 26 mm. (about 1 inch) in length and to 15 mm. (about 5/8 inch) in height, elongate-subelliptical, thin, fragile, with the right valve of a greater convexity and with a slight flexure to the right posteriorly. Umbos posterior to the middle, inflated and blunt. Anterior margin generally narrowly rounded; ventral margin straight to slightly convex and rising posteriorly; anterior dorsal margin long and gently sloping; posterior dorsal margin straight and short; posterior margin short and forming a poorly defined, oblique truncation. Sculpture consisting of closely set, weakly developed concentric lines; no true radial sculpture present. Ligament light to dark brown and slightly protuberant. Calcareous portion of the ligament subtended by slightly protuberant nymphal callosities. In the left valve, the cardinal complex consists of an anterior small, subdeltoid bifid tooth with subequal lobes and of a posterior, very thin, extremely elongate laminate tooth; a subproximal anterior lateral thickening represents a vestige of the anterior lateral tooth; no posterior lateral dentition. In the right valve, the cardinal complex consists of a posterior skewed bifid whose posterior lobe is much the larger and of an anterior short slightly thickened laminate tooth; the anterior lateral tooth is proximal to subproximal, thin, laminate and often weakly upcurled; no true posterior lateral tooth present. Adductor muscle scars moderately impressed. Anterior adductor muscle scar narrow and rounded below; posterior adductor scar subquadrate. Pallial sinus more or less the same in opposite valves, rising gently behind, rounded above, descending gently in a more or less straight line and falling in an arcuation to the pallial line; the sinus is distinctly removed from the anterior adductor scar. Externally, shell smooth, shining and suffused with pink or yellowish green; internally, chalky.

length	height	width	
26.5 mm.	15.0 mm.	7.0 mm.	Holotype of <i>diantha</i>
23.0	14.0	7.5	Totness, Coronie, Surinam
22.3	13.0	6.4	Rio de Janeiro, Brasil
22.0	13.0	6.0	Belem, Brasil
18.0	10.5	5.4	Totness, Coronie, Surinam

Types. The holotype of *Tellina (Angulus) diantha* is in the Museum of Comparative Zoology, no. 239110; type locality, Barbados, British West Indies.

Remarks. The relationship of this species with others obviously allied to it is obscured by its apparent rarity and the fact that no ontogenetic series of specimens has yet been collected. The large adult size of this species quickly distinguishes it from other members of *Angulus*, but such a character is undesirable as a diagnostic trait. The peculiarly elongate posterior cardinal tooth in the left valve possesses important diagnostic value. In addition, the width and general tumidity of the valves constitute a further aid in identification.

The closest relatives of this species are *Tellina euvitrea* and *T. probrina*. With respect to both of these species, *diantha* is more tumid and of a different outline, possessing a poorly differentiated posterior truncation and a comparatively shorter anterior dorsal margin with the umbo more nearly equilateral. The pallial sinus does not rise abruptly from the posterior adductor muscle scar and it extends more anteriorly than in either *euvitrea* or *probrina*.

A fine series of *diantha* has been found by Altena in Surinam. The series from Totness, Coronie, consists of two complete specimens plus five right valves and two left valves and are designated as paratypes for this species; the specimens are preserved in the Rijksmuseum van Natuurlijke Historie, Leiden.

Range. Although there are only a few records for the species they indicate a rather extensive range, from the Barbados in the Lesser Antilles south to Rio de Janeiro, Brasil.

Specimens examined. LESSER ANTILLES: Barbados (MCZ). SURINAM: Totness, Coronie (Rijksmuseum, Leiden). BRASIL: Belem, Para (MCZ); Rio de Janeiro (USNM).

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Anatomy and Relationships of *Temnoconcha brasiliiana* Dall

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The genus *Temnoconcha* has been previously known only from the holotype of the type species, *T. brasiliiana* Dall, which is figured herein for the first time. During the course of a revisionary study of the family Tellinidae, additional specimens of this species were found, including a single specimen suitable for dissection. The following notes were prepared to clarify the taxonomic position of the genus within the family and to present the known distribution of fossil and recent species in the genus.

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ABBREVIATIONS

MCZ—Museum of Comparative Zoology, Harvard University
IMBPR—Institute of Marine Biology, Puerto Rico

¹ United States Fish and Wildlife Service, Washington, D.C.

² Museum of Comparative Zoology, Harvard University, Cambridge, Mass.

USNM—United States National Museum

BMNH—British Museum (Natural History)

SYSTEMATIC NOTES

In 1921, Dall described *Psammacoma brasiliana*, creating for it a new section, *Temnoconcha*, on the basis of its unusual sculpture. The type locality of *brasiliana* is São Sebastian Island, São Paulo, Brasil. The holotype (USNM, no. 333023) measures 35 mm. in length, 23 mm. in height, and 8 mm. in width. The shell is characterized by finely incised and closely set transverse sculpture which crosses the external surface of the valves from a high point along the anterior dorsal margin to a low point along the ventral and posterior margins. This sculpture is out of phase with the concentric incremental sculpture. This mode of sculpture is also characteristic of the subgenus *Scissula* (type species, *Tellina decora* Say 1826 [= *Tellina similis* Sowerby 1806]). As *Temnoconcha brasiliana* does not possess lateral teeth in either valve, it is definitely not tellinoid, but macomoid.

Since *Temnoconcha brasiliana* is outwardly similar to *Tellina similis*, some confusion has resulted in the identification of the former species. For example, *brasiliana* was probably first seen by d'Orbigny, as in his collection, which is preserved in the British Museum (Natural History), specimens of Dall's species are labeled '*Tellina similis* Sowerby.' Plainly, d'Orbigny (1822; 1845; 1853) did not know Sowerby's species, for in 1842 he proposed the name *Tellina caribaea* for the common West Indian species which Sowerby had previously described as *similis*.

In his original description of *Temnoconcha brasiliana*, Dall noted the finer points of the hinge dentition, indicating that it consists of only two cardinal teeth in each valve. They depart from the usual macomoid pattern in that both cardinals in the right valve are bifid (see pl. 5, fig. c) while in the left valve, the anterior cardinal is bifid and the single posterior cardinal is laminate. Recently, Olsson (1961) noticed the same configuration in the Eastern Pacific species, *Tellina cognata* Adams 1852 (= *Tellina concinna* Adams 1852) and erected a new genus, *Psammothalia* with *cognata* as its type species. The name *Psammothalia* is therefore a junior synonym of *Temnoconcha* Dall. Olsson gave in the synonymy of *cognata* the various

genera and subgenera to which this species had been assigned previously, thus illustrating that many authors were aware of the peculiar affinities of *cognata*. The species was referred to *Psammobia* by Reeve, *Quadrans* by Dall, *Scissula* by Hertlein and Strong, and *Macoma* by Smith. Certainly, there is no question that *cognata* and *brasiliiana* belong to the same group and that they are extremely closely related. Differences between the two species are rather difficult to discern, but they are apparently distinguishable by the thickness of the valves and the width of the shell (see table of measurements). In *brasiliiana*, the umbo appears to be farther behind the middle, the shell is more compressed, and the individual valves are thinner than in *cognata*.

According to Olsson (1961), *cognata* is rather common and is widely distributed in the eastern Pacific, being found from Mexico to northern Peru. It is also represented in the Pliocene of Ecuador, and a fossil species in the Miocene of Ecuador appears in the ancestry of *cognata*. Specimens which Olsson referred to as occurring in the Gulf of Mexico have been studied by the authors and are *brasiliiana*.

In addition to the original type locality given by Dall for *brasiliiana*, the following records of specimens examined are listed and the range of this species is extended:

PUERTO RICO: Punta Algorrobo; Mayagüez (both IMBPR).

LESSER ANTILLES: Matura Bay, Trinidad; 2 miles S of Fort George, Scarborough, Tobago, in 36 fathoms (both MCZ).

HONDURAS: 17 miles NE of Lake Taratasca (Steger).

PANAMA: mouth of Rio Coclé del Norte.

VENEZUELA: 4.3 km. W of Barcelona (both USNM).

SURINAM: Paramaribo; Braams Punt, E of mouth of Surinam River (both Altena).

BRASIL: Praia Comprida, Vitoria, Estado do Espirito Santo (MCZ).

Temnoconcha has recently been collected in the Pleistocene of Surinam by Altena and the fossil species, *Tellina* (*Scissula*) *cercadica* Maury (1917) from the Miocene of Santo Domingo appears to be an ancestor of *brasiliiana*. *Temnoconcha brasiliiana* is apparently widely dispersed but rare.

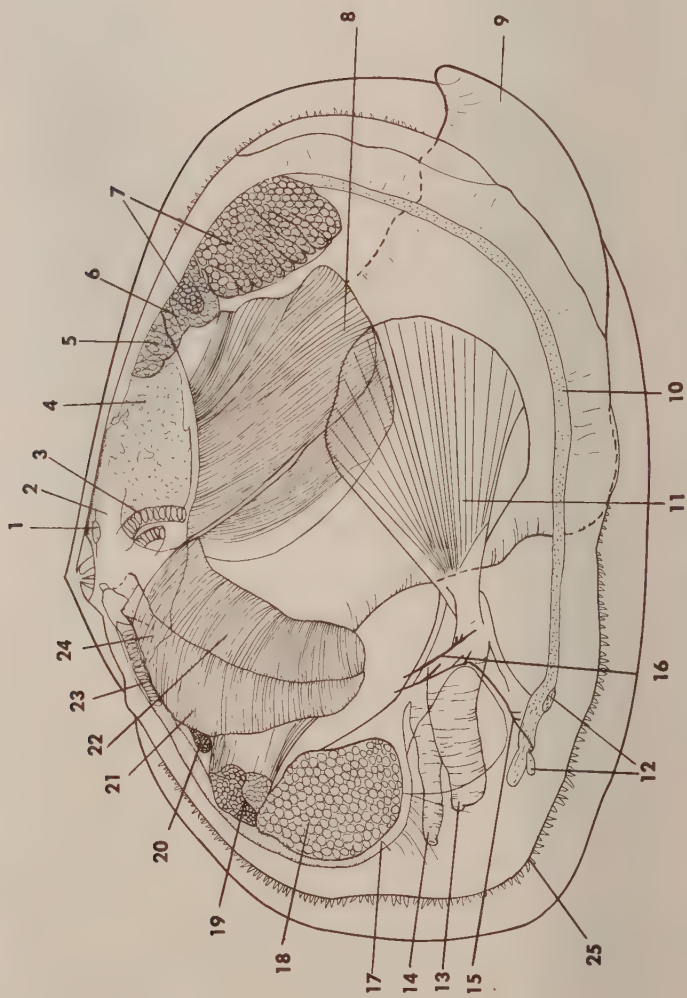


Plate 56

Semidiagrammatic illustration of the anatomy of *Temnoconcha brasiliiana*. Specimen with the right valve removed to show general external structural features.

1. medial muscle.
2. gonad.
3. intestine.
4. digestive gland.
5. anterior pedal retractor muscle.
6. pedal protractor muscle.
7. anterior adductor muscle.
8. labial palps.
9. foot.
10. pallial line.
11. siphonal retractor muscle.
12. cruciform muscle.
13. incurrent siphon.
14. excurrent siphon.
15. nerve to the cruciform muscle.
16. nerve to the siphonal retractor muscles.
17. anus.
18. posterior adductor muscle.
19. posterior retractor muscle.
20. kidney.
21. outer demibranch.
22. inner demibranch.
23. rectum.
24. pericardium.
25. tentacles of mantle.

cognata

length	height	width	
44.0 mm.	29.5 mm.	7.0 * mm.	Holotype of <i>cognata</i> , MCZ 186304
38.0	25.0	11.0	Lectotype of <i>concinna</i> Adams, MCZ 186302
37.5	24.5	10.5	Paratype of <i>concinna</i> Adams, MCZ 186303
53.7	35.8	15.1	Tumbez, Peru
65.5	41.0	9.0 *	Zorritos, Peru

brasiliiana

35.0	23.0	8.0	Holotype of <i>brasiliiana</i> , USNM 333023
28.0	19.5	7.5	Punta Algorrobo, Puerto Rico
29.0	10.0	—	d'Orbigny Collection (BMNH), no locality
23.5	16.0	—	" " " "
44.0	30.0	5.0 **	" " " "

* semiwidth, right valve only; ** semiwidth, left valve only.

ANATOMY

The mantle is thin and transparent over most of its surface but is thickened and muscular at its periphery where it attaches to the valves. It is united dorsally beneath the hinge line of the shell but open ventrally, except at the formation of the cruciform muscle and no specialized pedal gape is formed. As in other macomoids (Yonge, 1957), the mantle margin is differentiated into outer, middle, and inner lobes. Along the postero-ventral border of the mantle, the middle lobe is provided with small, elongate, transparent, and pointed tentacles (pl. 56). Shorter tentacles are present along the anterior dorsal margin of the edge of the mantle. A mantle fold or ridge, similar to that described by Yonge (1949) for *Abra* and *Scrobicularia*, extends from the vicinity of the cruciform muscle anteriorly to form a ventral channel (pl. 57 and pl. 58). The origin of the bilateral fan-shaped siphonal muscle is impressed as a muscle scar, called the pallial sinus, on the internal surface of each valve. The siphonal muscles are slightly asymmetric with those of the left side being somewhat larger. In consequence of this asymmetry, the anterior margin of the pallial sinus in the left valve is closer to the anterior adductor muscle scar. The siphonal musculature becomes confluent with the mantle musculature postero-ventrally; the posterior confluence of the pallial sinus and the pallial line in each valve reflects this anatomical feature.

The siphons are free along most of their length and are united basally. They are not tentaculate distally. At the proximal opening of the incurrent siphon where the inflow of water into the mantle cavity occurs, a right unilateral siphonal organ and bilaterally paired parasiphonal organs are found (pls. 57 and 58). The siphonal organ is thickened, plicate, and 'cushiony' and probably serves a function similar to that of the osphradium of gastropods. The paired parasiphonal organs, previously called 'valvule palleale' by Pelseneer (1911) or 'mantle folds' by Yonge (1949), are thin and phylloid. They function to prevent pseudofeces from being swept onto the gills by the strong incoming flow of water. Both these organs are attached to the inner surface of the walls of the siphonal musculature, and both are innervated by nerves from the visceral ganglion.

The cruciform muscle subtending the siphonal apparatus is well developed and possesses the small cruciform organs discussed and figured by Yonge (1949). The posterior portion of the cruciform muscle is divided near its origin, forming two small scars on each valve; the anterior portion has a single origin. Concordant with the asymmetry of the siphonal musculature, the anterior and posterior cruciform muscle scars are closer together on the left valve than on the right.

The anterior and posterior adductor muscles are large and subequal in size. The anterior adductor is subdivided into two portions of which the ventral is the larger; the muscle is irregularly elongate and semilunate in shape. The posterior adductor muscle tends to be subquadrate. Mediodorsally there is a small muscle which splays out in the mantle lateral to the convoluted intestine and attaches the visceral mass to the valves. This muscle is structurally different from but may be functionally similar to the medial adductor muscle which Yonge (1949) illustrated connecting the two valves and passing under the postero-dorsal caecum of the stomach in other tellinoids. This medial muscle leaves a distinct, variously formed scar just anterior and ventral to the cardinal hinge plate in both valves.

The pedal musculature consists of anterior and posterior pedal retractors and of a pedal protractor; all the complex of pedal musculature inserts into the foot. The anterior pedal retractor originates along the anterior dorsal margin of the

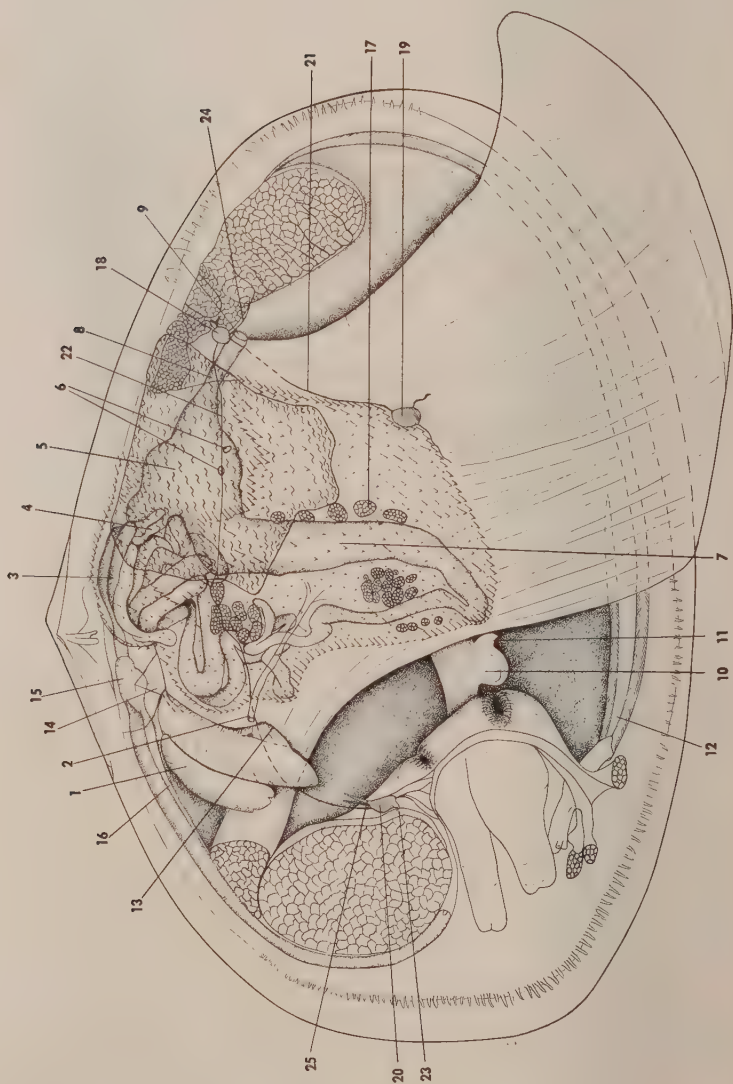


Plate 57.

Semidiagrammatic illustration of the anatomy of *Temnoconcha brasiliana*. Specimen with the mantle, ctenidia and palps removed to show internal features. Ovary indicated by check marks, digestive gland by wavy lines.

1. kidney.
2. oviduct.
3. convoluted portion of the intestine.
4. appendix.
5. stomach.
6. ducts to digestive gland on right side of stomach.
7. mid-gut and style sac.
8. esophagus.
9. mouth.
10. siphonal organ.
11. parasiphonal organ.
12. ventral channel.
13. nephroproct.
14. auricle.
15. ventricle.
16. posterior aorta.
17. transverse muscle (one of many).
18. cerebropleural ganglion.
19. pedal ganglion.
20. visceral ganglion.
21. cerebropleural-pedal connective.
22. cerebropleural-visceral connective.
23. nerve to posterior adductor.
24. nerve to anterior adductor.
25. branchial nerves.

valve and inserts deeply in the foot. The posterior pedal retractor originates dorsal to the posterior adductor muscle and courses anteriorly to insert in the foot beneath the fibers of the pedal protractor and intermeshing with the fibers of the anterior pedal retractor. The pedal protractor has a diffuse origin along the anterior dorsal margin between the anterior adductor muscle and the anterior pedal retractor. The pedal protractor splay out in a superficial insertion immediately beneath the heavy epidermal tissue of the foot. The foot itself is rather large and laterally compressed; its well developed retractor, protractor, and many transverse muscles reflect its strength and extensibility.

The gills of *Temnoconcha* are typically macomoid in form and placement. They consist of a dorsally upturned outer demibranch and a ventral inner demibranch. The individual demibranchs are united medially, and the combined demibranchs of the right and left ctenidia are united distally along the ventral surface of the posterior retractor muscle. Contiguous with the proximal boundary of the inner demibranch are the large labial palps which are similar to those of other macomoids (Thiele, 1886). The filter feeding mechanisms of *brasili-ana* are probably similar in function to those of *Macoma secta* as described by Kellogg (1915).

Plates 57 and 59 illustrate the structure of the alimentary canal. At the median union of the right and left pairs of labial palps is the mouth. A short esophagus leads to the stomach which is enveloped by the digestive gland. The stomach in the Tellinidae has been described in detail by Graham (1949) and Purchon (1960). In *brasiliana*, the style sac and mid-gut are united and leave the stomach postero-ventrally. The stomach has right and left ventral caeca, a dorsal pouch, and a postero-dorsal appendix. Two large ducts from the digestive gland enter the right ventral caecum and a single duct enters the left ventral caecum. The gastric shield differs markedly from that of *Tellina tenuis* as illustrated by Yonge (1949) in that it extends into the esophagus, the dorsal pouch, and the posterior portion of the stomach dorsal to the appendix. The intestine is tortuously convoluted before it passes through the ventricle of the heart in the pericardial cavity. The rectum extends from the pericardial cavity along the dorsal margin above the

ctenidium and the posterior adductor muscles, forming the terminal anus near the opening of the excurrent siphon. In the specimen dissected, the intestine and rectum contained coin-shaped fecal pellets (length/breadth ratio=0.5) which upon examination were found to consist of unidentifiable plant remains, including diatoms, and some sand grains with detritus, indicating the normal filtering habit of a benthic deposit feeder.

The heart is located postero-dorsally in the pericardial cavity. It is simple in form, consisting of laterally paired thin-walled auricles and a single thick-walled median ventricle through which the rectum passes. An aorta extends posteriorly from the ventricle along the ventral side of the rectum. The relatively large kidney which is postero-ventral to the heart connects with the pericardium via the laterally paired ciliated reno-pericardial funnels. Waste products from the kidney are expelled via the nephroproct.

Temnoconcha appears to be dioecious though only a female specimen was available for dissection. The large ovary is imbedded in the foot, surrounds the style sac, mid-gut, and the ventral portion of the digestive gland and extends dorsally and superficially over the convoluted portion of the intestine into the mantle tissue. The extension of the gonad into the mantle tissue has been reported in certain species of *Arca* and *Chama* (White, 1942). A long and branched oviduct leads to the genital pore which opens near the nephroproct in a urogenital sinus which is coextensive with the mantle cavity. Eggs in the ovary were 130–140 μ in diameter and quite yolky, indicating lecithotrophic larval development and a short pelagic stage. Odhner (1912) has discussed in detail the nephridial system and its relationship with the circulatory and reproductive systems in *Macoma balthica*, which in many respects is similar to *brasiliiana*.

The structure of the nervous system of *Temnoconcha* is similar to that of *Psammobia* as described by Durvernoy (1854). The cerebropleural ganglia, located on the inner surface of the anterior adductor muscle, are united via a cerebro-pleural commissure. Anteriorly the ganglia give rise to a branching complex of nerves which innervates the anterior adductor muscle as well as the anterior pallial musculature. The cerebropleural-pedal connectives extend ventrally from the cerebropleural

Plate 58

Ventral posterior view of *Temnoconcha brasiliiana* to show the structural features of the cruciform muscle and the siphonal apparatus.

1. tentacles.
2. rectum.
3. anus.
4. posterior adductor muscle.
5. excurrent siphon.
6. incurrent siphon.
7. cruciform muscle.
8. cruciform organs.
9. mantle fold forming ventral channel.
10. siphonal organ.
11. parasiphonal organ.
12. base of incurrent siphon.
13. foot.

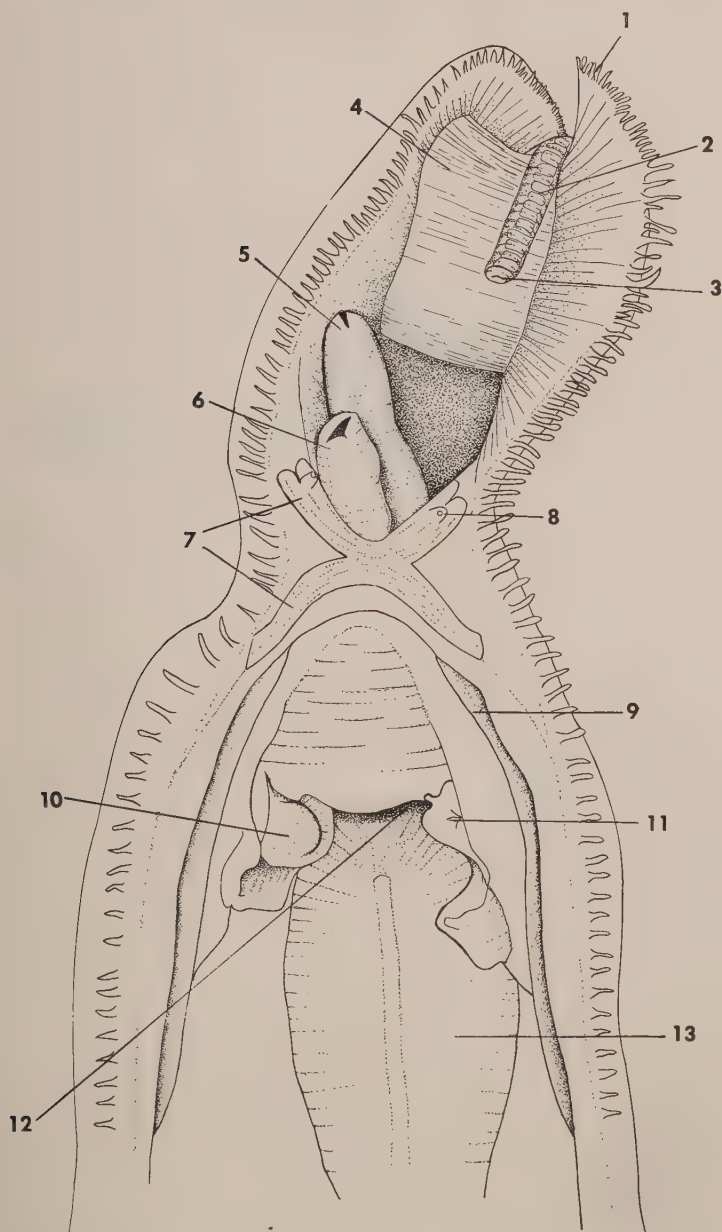


Plate 58

Plate 59

Upper figure. The style sac and stomach of *Temnoconcha brasiliiana* viewed from the right side. Lower figure. The gastric shield of *Temnoconcha brasiliiana* viewed from the right side.

1. style sac and mid-gut.
2. crystalline style.
3. appendix.
4. esophagus.
5. right ventral caecum.
6. gastric teeth.
7. extension to dorsal pouch.
8. extension to esophagus.
9. extension to style sac.
10. extension toward postero-dorsal appendix.

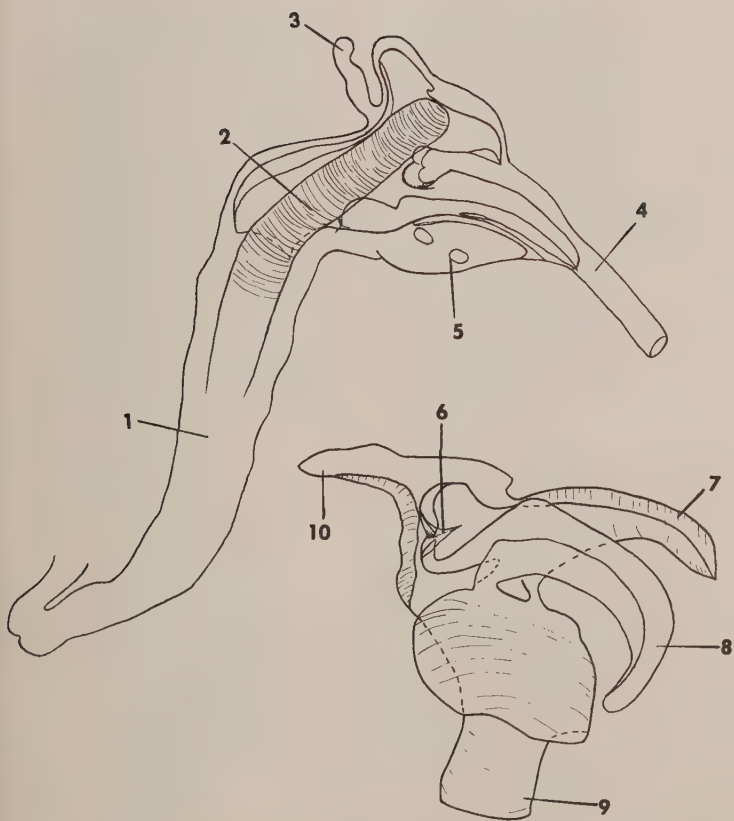


Plate 59

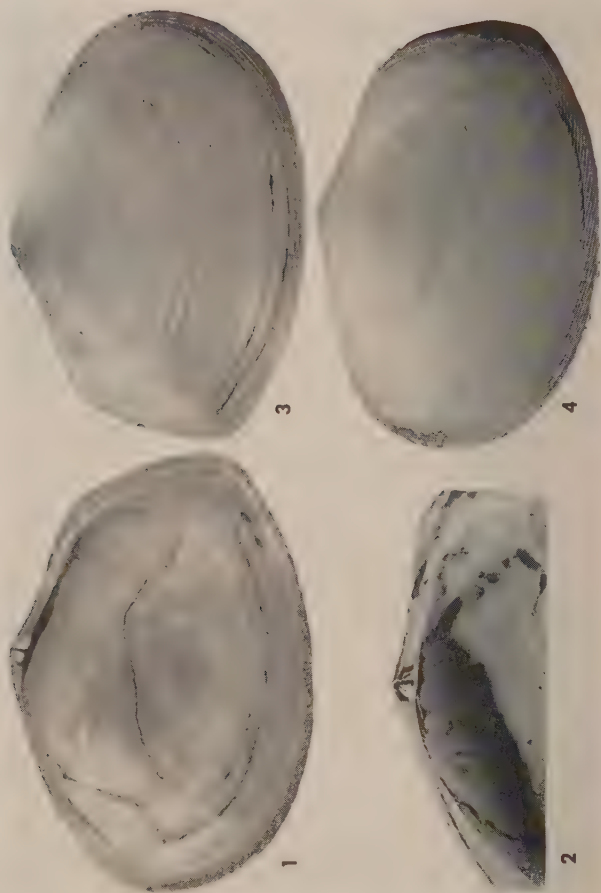


Plate 60

Plate 60

Fig. 1. Internal view of the right valve of the holotype of *Temnoconcha brasiliiana* Dall, showing configuration of the pallial sinus (1.8 $\times$).

Fig. 2. Internal view of a portion of the right valve of *Temnoconcha brasiliiana* Dall, showing the bifid cardinal teeth and absence of lateral teeth (specimen from the d'Orbigny collection, BMNH; 2.8 $\times$).

Fig. 3. External view of the right valve of the holotype of *Temnoconcha brasiliiana* Dall (1.8 $\times$).

Fig. 4. External view of the left valve of the holotype of *Temnoconcha brasiliiana* Dall (1.8 $\times$).

ganglia to the paired but closely juxtaposed pedal ganglia. From the pedal ganglia numerous branches innervate portions of the pedal retractor and protractor musculature as well as portions of the viscera extending into the foot. Arising from the cerebropleural ganglia and coursing posteriorly are the laterally paired cerebropleural-visceral connectives which communicate with the nearly fused, compacted visceral ganglia near the inner surface of the posterior adductor muscle. Paired nerves are given off to the ctenidia from the visceral ganglia and the posterior adductor muscle. The largest pair of nerves extends ventrally and gives off branches to the mantle, the siphonal musculature, the siphonal and parasiphonal organs, and the cruciform muscle.

RELATIONSHIPS

The affinities of *Temnoconcha* with the family Tellinidae are clearly shown by anatomical characters such as the formation of the gills and the muscles, the union of the style sac and the mid-gut, the simple structure of the heart, the dioecious condition of the reproductive system and the specialization of the nervous system. Within the family, the subfamilies Tellininae and Macominae may be distinguished by the presence or absence of lateral teeth, the relative size of the ctenidia and the labial palps, the degree of convolution of the distal portion of the intestine and the structure of the cruciform organs. The genus *Temnoconcha* has macomoid shell characters but is distinctive in the possession of two bifid cardinal teeth in the right valve. As in *Macoma*, the palps of *Temnoconcha* are larger than the ctenidia, the distal portion of the intestine is extensively convoluted and the cruciform organs open externally via tubular papillae. Therefore, *Temnoconcha* appears to belong to the subfamily Macominae.

Temnoconcha differs from other members of the Tellinidae for which the anatomy is known in the following characters: 1) the gastric shield is very complex; 2) the medial muscle splays out over the viscera dorsally rather than passing beneath the postero-dorsal appendix of the stomach; 3) the posterior portion of the cruciform muscle has a double rather than a single origin; and 4) the reproductive tissue extends into the mantle.

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Supplement to the Poison Cone Shell¹

By WILLIAM J. CLENCH

The following appeared anonymously in a newspaper under the title of "Natural History." I am indebted to Dr. D. F. McMichael of the Australian Museum, for bringing it to my attention.

The Sidney Mail, January 10, 1874, p. 50.

"A strange instance of poisoning occurred on the Island of Maré [Loyalty Islands, New Caledonia]. On a Monday morning the *John Williams* anchored off the station of the Rev. J. Jones. For a long time no notice was taken of our visit, not a canoe came off. When at last the missionary pulled off to us in his boat, we anxiously inquired the cause of delay.

"Mr. Jones had been burying a poor man who had been poisoned by handling a fish. After attending the services of the Sabbath, the thoughtless fellow went fishing on the reef at sunset. In the doubtful light he unhappily took up a good sized shell-fish and put it in his basket. He immediately felt a painful sensation running up his right arm to the shoulder. He went home. The pain increased until he writhed in agony. The body swelled to an enormous size and by daylight he was a corpse. So remarkable did this seem to me that I requested a sight of the shell-fish which poisons by the mere touch, although the skin be uninjured. The request was kindly complied with by the friends of the deceased; and the shell proved to be the *Conus textile*.

"This variety of shell-fish is well known to the natives of Western Polynesia for its dangerous qualities. A virulent poison is injected by means of numerous minute barbs connected with the mantle. These barbs somewhat resemble the sting of a bee."

¹ See *Occasional Papers On Mollusks*, 1946, 1: 49-80.

2 miles south of Pemaquid, Maine, at latitude $43^{\circ}48'$ N and longitude $69^{\circ}31'$ W.

The diagnostic characteristics used to identify the specimens were the shape of the lateral line and caudal fin, and ray counts of the dorsal and anal fin. The dorsal and anal fin ray counts listed by Norman (1934, *A systematic monograph of the flatfishes*, *Brit. Mus. Nat. Hist.* 1:289-290) were 94 to 102 (92) and 71 to 76, respectively. Goode and Bean (1895, *Oceanic ichthyology*, U. S. Natl. Mus. Spec. Bull.:435) reported 100 dorsal and 75 anal fin rays for adults, and 91 dorsal and 72 anal fin rays for a "young specimen." The counts for the fish reported in the present collection ranged from 96 to 98 dorsal rays and from 72 to 74 anal rays. The blind sides of the four fish were off-white in color (sooty), a character sometimes used to distinguish young Greenland halibuts from adults. The retainment of this off-white color on the blind side of the specimens, the largest of which was 32.0 cm, differs in part with the findings of Jensen (1925, *Medd. Komm. Dan. Fisk. Havundersøg., Ser. Fisk.* 7(7):9-17, 26-29). He reported that up to a length of 25.0 cm, the blind side of the fish was sooty in color, but from a length of 25.0 cm onwards, the blind side was always dark, approximating that of the eyed side. Fig. 1 shows the eyed and blind side of the 32.0-cm specimen.

According to Bigelow and Schroeder (1953, *U. S. Fish. Wildl. Serv., Fish. Bull.* 74(53):258-259), *R. hippoglossoides* is a fish of the arctic and subarctic Atlantic Ocean and has no "real place in the Gulf of Maine fish fauna." These authors reported that the southern limit of the species along the western Atlantic coast was the gully between La Have and Georges Bank, although in July 1952, 16 specimens were caught along the slope of La Have to the southwestern slope of Georges Bank. The catches were made in waters of 200 or more fathoms. Since 1952, Schroeder (personal communication) has recorded eight additional *R. hippoglossoides* taken in the same general areas between latitudes $40^{\circ}55'$ and $42^{\circ}41'$ N and longitudes $63^{\circ}47'$ and $66^{\circ}20'$ W, all from waters of 360 to 600 fathoms. In more northern waters, the fish has been caught at shallower depths. Jensen (1935, *Mem. Acad. R. Den., Ser. 9* 6(4):1-35) reported that in Greenland waters the species occurred at depths of 135 to 800 fathoms. Hansen (1943, *Ann. Biol.*

OCCURRENCE OF THE GREENLAND HALIBUT, *REINHARDTIUS HIPPOGLOSSOIDES* (WALBAUM), IN SHALLOW WATERS IN THE GULF OF MAINE.—During February 1963 four specimens of the Greenland halibut, *Reinhardtius hippoglossoides* (Walbaum), were caught near Boothbay Harbor, Maine, by the trawlers TIPSYPARSON and HILDA L. These fish with total lengths (in cm) of 32.0, 26.1, 27.2, and 26.4 weighed 214, 99, 148, and 101 g, respectively. Two specimens were caught at a depth of 50 to 55 fathoms, one 6 miles south of Seguin Island, Maine, at latitude $43^{\circ}37'$ N and longitude $69^{\circ}45'$ W, the other approximately $8\frac{1}{4}$ miles from Pemaquid, Maine, at latitude $43^{\circ}42'$ N and longitude $67^{\circ}27'$ W. The other specimens were taken at a depth of 35 to 40 fathoms,

50:119) reported that specimens used for marking experiments in West Greenland were always taken with long lines from depths of approximately 100 to 250 fathoms. Dr. W. Templeman, St. John's, Newfoundland, Canada (personal communication), reported Greenland halibut have been taken from 96 to 106 fathoms in Conception Bay, Newfoundland. He stated that commercial-size catches in the Newfoundland-Baffin Island area occur most frequently in depths from 180 to 300 or more fathoms. Dr. E. Smidt, Charlottenlund, Denmark (personal communication), reported that, in Greenland waters, *R. hippoglossoides* have been taken occasionally with long lines from depths of about 55 to 60 fathoms, but to obtain commercial quantities, the lines must be set 125 fathoms or deeper.

The Gulf of Maine waters in which the specimens were obtained have been fished frequently by local trawlers. Fishermen from these trawlers often bring unusual specimens

to the U. S. Bureau of Commercial Fisheries Biological Laboratory, Boothbay Harbor, Maine, for identification. Several of these fishermen were shown the fish, and none could recall ever having caught anything similar. No collection record is available for *R. hippoglossoides* at the laboratory, nor is there any known record of its occurrence in waters as far south other than the deep-water specimens mentioned by Bigelow or Schroeder (personal communication). The presence of these specimens in the Gulf of Maine is an important addition to their known range. Of equal importance is that the fish were from the shallowest depth of capture ever recorded. The water temperatures in the area of capture were 1.5 to 2.5°C colder than in the past 3 years. The southern extension of this subarctic species in the Gulf of Maine may have been related to these lower temperatures.—H. C. BOYAR, U. S. Bureau of Commercial Fisheries, Biological Laboratory, Boothbay Harbor, Maine.

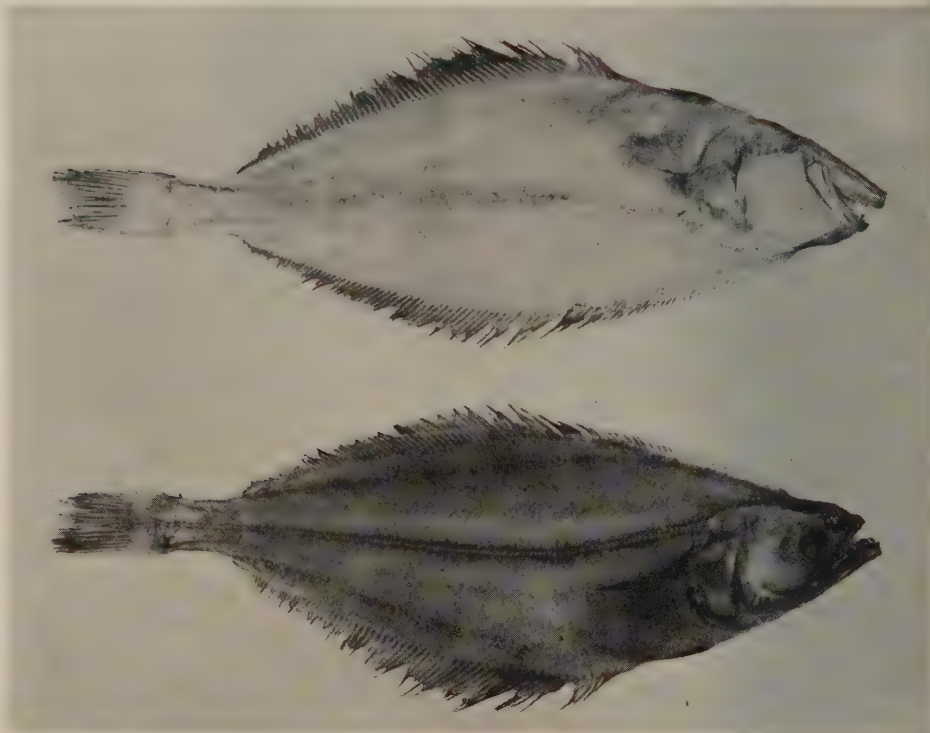


Fig. 1. Eyed and blind side of *Reinhardtius hippoglossoides* (Walbaum) (32.0 cm T.L.) caught at a depth of 50-55 fathoms.

U.S. FISH AND WILDLIFE SERVICE • J. L. Buckley and M. G. Hanavan

International treaties and Federal laws place United States' responsibility for the conservation and management of fish and wildlife in the Department of the Interior, Fish and Wildlife Service. The Bureaus share these responsibilities, with the Bureau of Sport Fisheries and Wildlife concerned with sport fisheries, migratory birds and walrus, polar bear, sea otter, and the Bureau of Commercial Fisheries concerned with commercial fish and shellfish, seals, sea lions, and whales.

Bureau of Sport Fisheries and Wildlife (J. L. Buckley)

In carrying out its responsibilities, the Bureau of Sport Fisheries and Wildlife conducts research, administers refuge areas, and enforces certain Federal laws relating to fish and wildlife. These responsibilities apply equally to arctic regions of the United States — specifically, Alaska and its contiguous seas.

Until Alaska became a state, the Bureau served in the territory the same function as a state fish and game department — i.e., it was responsible for the management of all fish and wildlife. With the advent of statehood, the State assumed responsibility for conservation of resident fish and wildlife.

Today, the Bureau of Sport Fisheries and Wildlife cooperates with the Alaska Department of Fish and Game in its management activities through Federal Aid in Fish and Wildlife Restoration programs and in joint support (with the University of Alaska and the Wildlife Management Institute) of the Alaska Cooperative Wildlife Research Unit. Studies presently underway at the Unit touch upon a wide variety of species, including several of the furbearers, the snowshoe hare, the harbor seal, and grizzly bear, and upon many aspects of ecology including effects of fire on wildlife and relations of red squirrels and white spruce.

The Bureau's own program in arctic and subarctic Alaska consists of protection of migratory birds, especially waterfowl; of research on sea otter, Pacific walrus, and migratory waterfowl; and of management of 14 refuge areas aggregating nearly 19 million acres.

Most Bureau studies are aimed at better management of wildlife resources, but, to accomplish this broad objective, studies of life histories, distribution, population ecology, and environmental requirements are requisite and make considerable contribution to basic knowledge. Major emphasis is on species of economic importance, or

unique or endangered species. Studies of sea otter and walrus life histories and distribution and of waterfowl production are currently receiving most emphasis. As a result of complete protection, and with the aid of knowledge gained from research, sea-otter populations have increased from near extinction to levels that now are sustaining experimental harvests.

Nestlings of the Rough-legged hawk, *Buteo lagopus*, a predator often encountered on bluffs along many arctic rivers.



Each of the National Wildlife Refuges or Ranges includes a unique environmental complex, for the most part free of artificial disturbance. Those that offer particularly attractive possibilities for research are 1) the Arctic National Wildlife Range in northeast Alaska containing 8.9 million acres ranging from subarctic forests through rugged arctic mountains to coastal tundra, 2) the Bering Sea Refuge with its introduced reindeer herd, 3) Nunivak Island National Wildlife Refuge with its herds of muskoxen and reindeer, 4) the Clarence Rhode National Wildlife Range on the Yukon-Kuskokwim Delta with its populations of nesting black brant and emperor and cackling geese, and 5) the Aleutian Islands National Wildlife Range with its unique flora and fauna, including the sea otter. Many smaller refuges protect nesting sea-bird colonies. At present, there is little opportunity for financial support by the Bureau for studies on these areas; hopefully, this situation will change in the future.

2. Bureau of Commercial Fisheries (M. G. Hanavan)

Arctic fishery research by the Bureau of Commercial Fisheries has greatly expanded in recent years in response to expansion of the Japanese and Soviet fisheries to the central North Pacific Ocean and eastern Bering Sea and in response to proposed hydroelectric power developments on the Yukon River.

The valuable red-salmon runs of Bristol Bay migrate through Bering Sea to spawn in the rivers and lakes. During much of their oceanic life, they are exposed to an intensive Japanese high-seas fishery. By international agreement, research has been carried on since 1955 to identify continent of origin of salmon,

to define the areas in which Asian and North-American salmon intermingle, and to estimate the numbers of North-American red salmon intercepted by the high-seas fishery. These studies are expanding our knowledge of the distribution and ocean migrations of all five species of Pacific salmon. Our understanding of their growth, survival, and the nature of their environment has grown through an intensive oceanographic research program in the subarctic North Pacific and Bering Sea.

Expansion of foreign bottomfish fisheries in eastern Bering Sea and the Gulf of Alaska has required research on such valuable species as king crab, halibut, and shrimp. King crab have been studied by Bureau scientists for several years with emphasis on life history, migration, and population dynamics. Research on halibut is largely the concern of the United States-Canadian International Pacific Halibut Commission. The research program seeks definition of halibut nursery areas in eastern Bering Sea, migrations between regulatory areas, and population studies to achieve maximum yields.

The Yukon River is noted for chinook and chum-salmon populations that migrate to spawning grounds located 1,500 to 2,000 miles above tidewater, well within the Yukon Territory of Canada. Although these runs are not of great commercial importance, they are substantial and are essential to the economy of many native villages in Alaska and Canada. A proposal to build a high hydroelectric dam at Rampart, more than 700 miles above the mouth of the Yukon River, called for intensive study of the salmon runs to determine their size and to devise means by which they could be maintained.

Fur-seal research has increased under the present terms of the International

Fur Seal Commission. Once limited population studies on the Pribilof Islands, it now includes research on pelagic habits of the fur seal from Bering Sea to Japan and California. Cooperative tagging programs by the United States and the U.S.S.R. measuring the interchange of individuals between the Pribilof, Commander, and Robben Islands. There have been several exchanges of scientists between U.S.S.R. and the United States. Research findings are exchanged at annual meetings of the Commission.

Eskimos living in the arctic villages of Point Hope, Barrow, and Wainwright are partly dependent for subsistence on the bowhead or Greenland right whale. This species was virtually exterminated by commercial whalers during the 19th century, but, under complete protection (except for native subsistence) afforded by the International Whaling Commission, their numbers are now increasing. Biologists observe the native hunt each year to estimate the abundance of whales and to obtain biological data.

Project Chariot, a proposal by the Atomic Energy Commission to demonstrate the feasibility of harbor construction by atomic excavation, required cooperation of several governmental and university research groups. The site selected for the experiment is on Chukchi Sea, north of Bering Strait. In 1959 the Bureau of Commercial Fisheries biologist John N. Cobb completed a biological survey of the region.

The growing world need for protein will require additional research as facilities become available. More knowledge of salmon runs to far northern rivers is needed. Conservation of shrimp and other underutilized Arctic resources also must depend on improved understanding of their biology.

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A TECHNIQUE FOR SEPARATING SMALL MOLLUSKS FROM BOTTOM SEDIMENTS

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ABSTRACT

Studies of the soft-shell clam, Mya arenaria, in New England required frequent examination of bottom samples in which clams ranged in length from 0.3 to approximately 100 mm. To facilitate separating smaller clams from sediments, a technique combining the advantages of screening, elutriating, and decanting was developed. The method has been used successfully with six other species of pelecypods and gastropods and appears adaptable to other species of unattached mollusks.

INTRODUCTION

Studies of the soft-shell clam, Mya arenaria, at the U. S. Bureau of Commercial Fisheries Biological Laboratory, Boothbay Harbor, Maine, from 1950 to 1960, required frequent, quantitative examinations of bottom samples. The size (length) of Mya in the sediments ranged from 0.3 to about 100 mm. The larger clams (over 5 mm) were not difficult to sort, count and measure, but the smaller clams required a special technique for efficient recovery.

Many workers have used flotation or screening methods, or various combinations of the two, in separating particular fractions. Pfitzenmeyer (1956) used screening alone to obtain 0.3 to 0.5 mm Mya. However, he used specially prepared trays containing fine sediments to collect new set, then passed the sediments through a fine screen which retained the clams. Sellmer (1956), working with Gemma gemma, first screened his samples, then separated mollusks from sand in a solution of zinc chloride. Anderson (1959) reviewed a number of flotation techniques and used a sugar solution to remove certain invertebrates from fresh-water benthic samples, but indicated the method was not as satisfactory for mollusks. Teal (1960) also used a sugar solution combined with screening and centrifuging in working with core samples, but was mainly concerned with recovering nematodes and arthropods. Williams (1960) utilized the activities of live fresh-water

invertebrates which would move from the original sediment sample into a covering layer of fine sand, from which they could be removed by screening. When organic detritus was present he floated the animals out in a solution of magnesium sulfate.

COLLECTION AND PRELIMINARY HANDLING OF SAMPLES

Subsamples for processing in the laboratory were taken from the surface of the clam flats, measured 6 inches square by 2 inches deep, and included the smallest clams. The clams deeper than 2 inches were sufficiently large to be readily dug out or screened in the field.

The laboratory sample was divided into two portions. The upper half-inch ("surface portion") was skimmed off. This layer included the smallest clams, ranging from 0.3 to approximately 5 mm. The remainder of the sample, the "subsurface portion," included clams ranging in size from 5 to 20 mm.

LABORATORY SEPARATION

Step 1

The subsurface portion was placed in a MacDonald hatching jar for elutriation¹ (see Figs. 1 and 2). A jet of water was introduced at the bottom of the jar through a glass tube constricted at the end. The flow which would remove the maximum amount of sediment without loss of clams was found by examining the overflow (A in Fig. 2). Any number of subsurface portions could be started through this initial step at the same time.

Step 2

The surface portion was first washed down through a series of seven screens, each 8 inches in diameter. The mesh sizes, from top to bottom, were 2.6, 5, 10, 18, 38, 52, and 70 meshes per inch. The first two screens retained pieces of shell or other large particles. All clams larger than 2 mm were retained on the 10- and 18-mesh screens. The contents of these screens were washed into separate white enamel trays, from which the clams could be readily picked with forceps.

¹ The term "elutriate" is used throughout in its common but more restrictive sense, meaning "to separate lighter particles from heavier by washing."

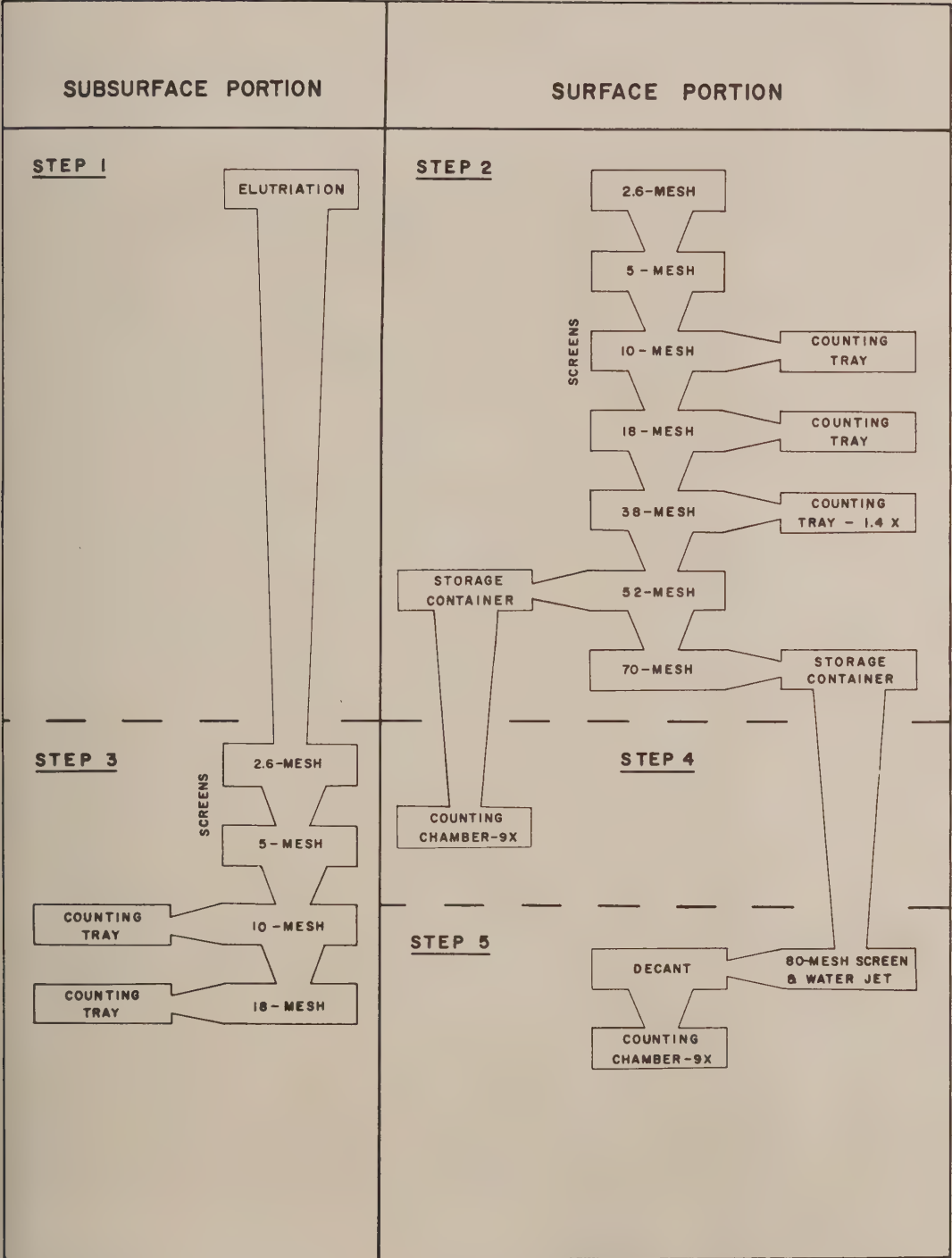


Fig. 1. Flow diagram indicating the sequence of separation and the progression of the two portions of a given sample.

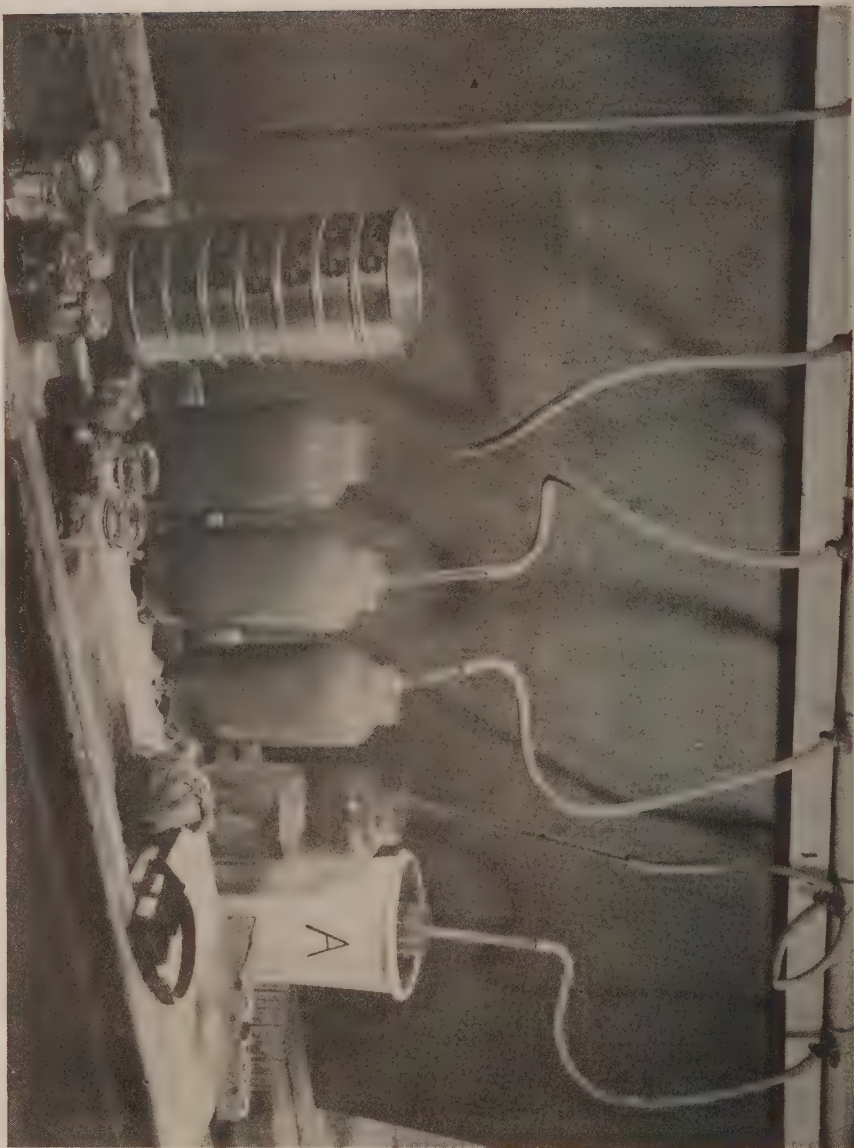


Fig. 2. Equipment used to separate mollusks from sediments. From left to right, the 8-inch diameter screens, the MacDonald jars used for elutriation, and A, the container used to establish the maximum flow from the jars.

The contents of the 38-mesh screen, which included clams between 1 and 2 mm long, were also washed into an enamelled tray, but a 1.4X magnifier and pipette were necessary to locate and remove the clams. The 52- and 70-mesh screens retained the rest of the clams in the sample, all of which were in the size range of 0.3 to 1 mm.

Step 3

When the elutriation of the subsurface portion had been completed, the remaining sediment was washed down through a series of four screens with mesh sizes of 2.6, 5, 10, and 18. The larger clams could be picked directly off the 2.6- and 5-mesh screens. The contents of the 10- and 18-mesh screens were washed out into separate enamelled trays for examination and removal of the clams. Excess organic detritus was decanted from the tray and the clams were then removed with forceps.

Step 4

The contents of the 52-mesh screen, obtained in Step 2, were washed into a 150-mm petri dish which had a 10-mm counting grid engraved in the bottom. With the aid of a 9X stereoscopic microscope the clams, ranging in size from 0.5 to 1 mm, were removed with a pipette. When a sample included much organic detritus, the sample was stirred with water in the petri dish and the lighter detritus was carefully poured off, leaving the clams and heavier sediments.

Step 5

The material from the 70-mesh screen, obtained in Step 2, was placed in a 3-inch diameter, 80-mesh screen with an 18-mesh screen on top and washed with considerable force until the water coming through was no longer muddy. The contents of this 80-mesh screen were then washed into the grid-marked petri dish and the lighter detritus was decanted from the dish as described in Step 4.

When the contents of the 70-mesh screen, obtained in Step 2, included so much sand that the clams could not be found readily, the contents were washed into a plain 150-mm petri dish. A rapid oscillatory motion of the dish brought the clams to the surface of the sand and they were quickly decanted into the petri dish with the counting grid. The clams, ranging in size from 0.3 to 0.6 mm, were found with the aid of the 9X microscope and removed with a pipette. The decanting process was repeated until no more clams were found.

DISCUSSION

To take fullest advantage of the time-saving features of the technique described herein, we adapted the various steps to the characteristics of the animal being sampled and the sediments in which it was found. With Mya arenaria from Maine, for instance, we found that in a year-round sampling program the 52- and 70-mesh screens (and therefore Steps 4 and 5) could be omitted from late October to early June. This was possible because the metamorphosed larvae did not set before early June, and by late October the setting had ceased and all clams were at least 1 mm long.

In a limited test to determine the time required for processing we utilized samples from a variety of bottom types, containing various numbers and sizes of clams. The processing time (not including removal of the tiny clams from the 52- and 70-mesh screens) for five such samples varied from 11 to 19 minutes and averaged 15 minutes per sample.

The technique described here has also proved successful in separating the following mollusks from the sediments: Mercenaria mercenaria, Macoma balthica, Petricola pholadiformis, Hydrobia minuta, Gemma gemma, and Mysella planulata. The method appears to be adaptable to the separation of most unattached pelecypods and gastropods from the sediments.

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Suborder Argentinoidea¹

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1. Also known as Opisthoproctoidei. I agree with Hubbs (26: 96) that it seems incongruous to name a group for its most bizarre member and therefore follow the suggestion of Bertelsen (6: 7) that the group be called the Argentinoidea, after one of the more generalized and better known genera. In the absence of any specific directive from the International Commission on Zoological Nomenclature concerning the derivation of subordinal names, the above procedure seems permissible, especially since the name Opisthoproctoidea, first used by Berg (4: 248, 433), has not gained particularly wide usage. Indeed, if strict priority were to be applied, it would be necessary to use the name *Platygastrichthyes* (37: 177) as it is the earliest designation of a suprafamilial category for a fish of this group.

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*History Museum. The late William Beebe and Miss Jocelyn Crane of the New York Zoological Society have sent me photographs and drawings. Hans Tambs-Lyche of the University of Bergen has generously furnished me with bibliographic aid and unpublished information. Arni Fridriksson of the Conseil International pour l'Exploration de la Mer provided a resumé in English of one of his papers written in Icelandic. Robert Wilson and H. J. Squires made unpublished information available to me. G. E. Maul sent information on the type of *Bathylagus longirostris*. E. Bertelsen allowed me access to several of his then unpublished manuscripts and was most cooperative throughout the entire course of my studies. Finally, I thank Mrs. Marion Grey, Giles W. Mead, William A. Gosline, and George S. Myers for their comments on portions of the manuscript.*

Characters. Body shape variable; elongated and subcylindrical in some, fore-shortened and compressed in others.

Dorsal fin generally close to center of body length. Caudal fin forked. Adipose fin present in most species.

Jaw mechanism and dentition greatly reduced with a tendency for the vomer and palatines to take over functions of the premaxillary and maxillary. Maxillary and mesopterygoid bones toothless. Premaxillary absent in some of the more specialized genera, lacking teeth when present.³ Supramaxillary absent. Metapterygoid much reduced.

Eyes variously directed; in some species laterally, in others dorsally or dorso-laterally, and in two species anteriorly; some species with tubular eyes.

Ventral arm of preopercle extending far forward, usually to the level of anterior edge of orbit. Branchiostegal rays 2 to 6.

Swim bladder absent in some genera and apparently always physoclistous when present.

Specialized light organs present in a number of genera, sometimes associated with a tubular eye. No serial photophores along sides of body. As far as known, eggs and larvae of all species pelagic.

Remarks. Fishes referable to this Suborder have been variously classified among the Clupeoidea, Stomiatoidea, and Salmonoidea. It is only since the relatively recent work of Chapman⁴ that the concept of the argentinoid fishes as a closely related group has developed. While the tendency formerly was to recognize as many as eight families, Hubbs (26: 96) has more recently combined all species into a single family. In this study a middle course is followed by recognizing three families, which I believe represent three distinct evolutionary lines.

In the Argentinidae are placed the closely related genera *Argentina* and *Glossanodon* (subfamily Argentininae) and the genera *Nansenia*, *Microstoma*, and *Xenoph-*

3. The weak premaxillary teeth attributed to argentinoid fishes by a number of authors have invariably been found to be rows of dermal papillae.

4. See 12: 1-22 for references.

*thalmichthys*⁵ (subfamily Microstomatinae). Although these two subfamilies are easily differentiated on the basis of habits and external characters, a consideration of the anatomy suggests close relationships.⁶

The genus *Bathylagus* stands as a separate family. Although some species of *Bathylagus* show striking similarities to some species of the argentinid genus *Nansenia* with regard to general body proportions and dentition, an examination of the internal anatomy verifies Chapman's reasons (II: 147-160) for maintaining *Bathylagus* as a family separate from the argentinids. The resemblances between some species of these two genera may well be an example of parallel evolution, for some of the species in each genus are silvery colored oceanic fishes of the upper water layers.

The remaining genera are placed together in the family Opisthoproctidae. In early osteological studies of some of these fishes they were placed in as many as five families (IO: 272-304). Some of the genera represent rather extreme forms, and considering their bizarre appearances, such treatment is not surprising. But capture of two additional specimens of *Rhynchohyalus natalensis* and the presentation of adequate figures and descriptions (33 [1946]: 62-65; 24: 87-90) pointed at once to the unity of this group. *Rhynchohyalus* has the elongated snout and orbital light organs of the slender species in the *Dolichopteryx-Bathylchnops* group, combined with the laterally compressed and deepened bodies of the *Macropinna-Winteria-Opisthoproctus* group. A unifying factor in all of the opisthoproctid fishes, indeed in all the argentinoid fishes, is the modification of the skull bones for the support of the greatly enlarged or tubular eye combined with the tendency toward a much-reduced jaw apparatus.

Range. Argentinoid fishes have not yet been taken in most parts of the Arctic Ocean or in the central and eastern parts of the South Pacific Ocean. Aside from these they are found in all other seas of the world.

Key to Families and Subfamilies

- 1 a. Parietals meeting in the midline; postcleithra present. Argentinidae, p. 4.
 - 2 a. Pectoral fins on the ventrolateral contours of body; lateral-line scales not extending onto caudal fin; mesocoracoid present; supratemporal lateral to and in contact with the lateral edge of the parietal and fused to the pterotic. Subfamily Argentininae, p. 4.
 - 2 b. Pectoral fins on sides of body; lateral-line scales extending onto caudal fin; mesocoracoid absent; supratemporal not in contact with the lateral edge of the parietal and not fused to the pterotic. Subfamily Microstomatinae, p. 23.
- 1 b. Parietals separate in the midline; postcleithra absent.
 - 3 a. Supraorbital bones present; interorbital space greater than 0.5 of the least

5. See Bertelsen (6: 7) for comments on the position of this genus, which he places with *Nansenia* and *Microstoma* in the Microstomidae.

6. Chapman (12: 19) has pointed out that in *Nansenia* and *Argentina* the parietals meet in the midline, and postcleithra as well as swim bladders are present. None of these conditions is found in *Bathylagus*.

depth of caudal peduncle; eyes not tubular; no photophore associated with the eye. Bathylagidae, p. 34.

- 3b. Supraorbital bones absent; interorbital space less than 0.5 of the least depth of caudal peduncle; eyes tubular, or with an orbital photophore, or both.

Opisthoproctidae, p. 48.

Family ARGENTINIDAE

Characters. Generally elongated fishes with some silvery pigmentation on head and along sides. Anal fin originating on posterior fourth of body. Pectoral fins originating close to posterior end of head. Ventral fins inserted on ventral surface of body. Eyes large and directed laterally in all genera except *Xenophthalmichthys*. Supraorbital bones present. Photophores or other luminous tissue apparently lacking. Frontals not fused; parietals meeting in the midline; postcleithra and a premaxillary present. Swim bladder present. Teeth present on vomer and palatines, present or absent on tongue, dentaries, and branchial arches. Pseudobranch well developed, lateral to and somewhat smaller than upper arm of first gill arch. Opisthotic reduced; orbitosphenoid present. Interopercle and ventral arm of preopercle extending forward to the level of anterior edge of eye.

Subfamily ARGENTININAE

Characters. Body elongated but not subcylindrical, at least in adults; many and perhaps all species with the body in the shape of an elongated, angular box (when scales are present); a cross section would show a polygon of 6 to 10 sides, depending on the location of the section and perhaps on the species as well. Eyes nontubular and with adipose eyelids,⁷ on sides of head. Head broader dorsally than ventrally, its sides sloping inwards ventrally, thereby giving the fish a ventral as well as a lateral field of vision. A crescent of white tissue of unknown function over dorsal or posterodorsal segment of iris. Snout longer than half the diameter of eye. Nostrils at level of upper third of eye and usually slightly closer to eye than to snout; a small flap on posterior nostril. Gill membranes separate. Branchiostegals 4 to 6. Lateral line originating slightly below dorsal angle of opercle and running straight back to base of caudal fin; lateral-line scales not extending onto caudal fin, and not larger than the other body scales. A scale sheath over proximal portion of folded ventral fins in most, and perhaps in all of the species. Dorsal fin originating closer to origin of ventral fin than to origin of pectoral fin. Distance from origin of ventral fin to origin of anal fin equal to or greater than distance from origin of ventral fin to origin of pectoral fin. Dorsal adipose fin over anal fin base. Pectoral fins inserted on ventrolateral contours of body.

Supratemporals lateral to and in contact with parietals, and fused to the pterotics. Mesocoracoids present. Frontals, in the interorbital region, broad and not fused.

7. Sometimes only the barest remnants are present in examples long immersed in preservative.

Lachrymal not in contact with eye but set forward a distance approximately equal to width of pupil; space between anterior edge of eye and posterior edge of lachrymal occupied by hyaline tissue which projects posteriorly as the adipose eyelid. Teeth on palatines, head of vomer, ceratobranchials of fifth gill arch, and suprabranchials of fourth gill arch.

Remarks. The eggs and young are apparently pelagic in waters above the continental shelf, although pelagic stages may occasionally be swept quite far out to sea. In many of the species the larvae and postlarvae have a row of dark, transverse bands on



FIGURE 1. Vomer of *Argentina elongata* (left) and of *Glossanodon semifasciatus* (right). From Cohen (14).



FIGURE 2. Tongue of *Argentina sphyraena* (left) and of *Glossanodon semifasciatus* (right). From Cohen (14).

the sides. These become reduced to dusky blotches along the dorsal half of the body in adolescents of most species and persist into the adult stage of a few species.

Although the life histories of most species of argentinine fishes are poorly known, catch records indicate that the adults are most commonly taken close to the bottom near the margins of the continental shelf. Commercial trawls have caught more specimens than any other gear, but these fishes have never contributed significantly to a commercial fishery.

Range. Species in this subfamily are known in the western North Atlantic from the central Labrador coast to the mouth of the Amazon. In the eastern Atlantic and adjacent waters, the group is represented off Iceland and in Denmark Strait, off Spitsbergen and Bear Island, south along the European coast to the Adriatic, off Israel, along the Mediterranean coast of Africa from Tunisia to the Strait of Gibraltar, near the Canary Islands, off Sierra Leone, and off French Equatorial Africa. In the Pacific the group is found from the mouth of the Columbia River to the Gulf of California, and in the seas surrounding the southern half of Japan, both in the Pacific and in the Sea of Japan, where a species is found off southeastern Korea. The group also is represented off southeastern Australia from New South Wales to western Australia, off New Zealand, around Tasmania, and at the Chatham Islands. Finally, a species is known from the western Indian Ocean.

Genera. The fishes of this subfamily have long been placed in the genus *Argentina*; however, I have shown (14: 93-172) that the species are divisible into two well-differentiated groups.

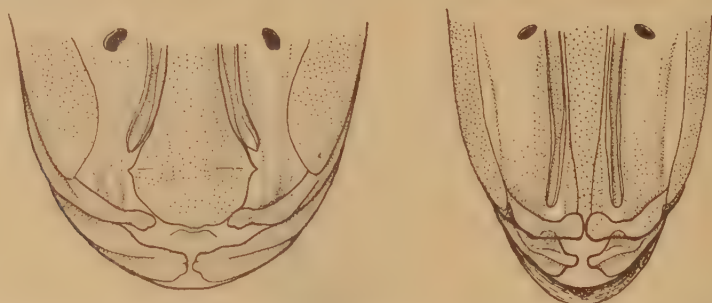


FIGURE 3. Dorsal view of snout of *Argentina striata* (left) and of *Glossanodon semifasciatus* (right), drawn from alizarin preparations. From Cohen (14).

Key to Genera

- 1 a. Vomerine and palatine teeth in a continuous band of closely spaced, posteriorly directed teeth, the former located less than a tooth's length behind anterior edge of head of vomer; tongue with teeth on front and lateral edges; medial ends of maxillaries separated by at least 0.5 of the width of the broad, underlying mesethmoid (Figs. 1, 2, and 3, left). *Argentina* Linnaeus 1758, below.
- 1 b. Vomerine and palatine teeth not in a continuous band of closely spaced, posteriorly directed teeth, the former located 3-8 tooth-lengths behind anterior edge of head of vomer; tongue teeth, when present, located at front of tongue, not along its lateral edges; medial ends of maxillaries touching in midline or separated by less than 0.25 of the width of the narrow, underlying mesethmoid (Figs. 1, 2, and 3, right). *Glossanodon* Guichenot 1867, p. 16.

Genus *Argentina* Linnaeus 1758

Argentina Linnaeus, Syst. Nat., ed. 10, 1, 1758: 315; type species by monotypy, *Argentina sphyraena* Linnaeus 1758. Mari Infero.⁸

Generic Synonyms:

Silus Reinhardt, Bemärk. Skand. Ichthyol., 1833: 11; type species by absolute tautonymy, *Salmo silus*⁹ Ascanius 1775. Bergen, Norway.

Goniosoma Costa, Fauna Napoli, Pesci, 3, 1844; type species by monotypy, *Argentina sphyraena*¹⁰ Linnaeus 1758. Naples.

8. Linnaeus cited Artedi (2: 8) who gave "Mare Inferum ad Romam" etc. as locality.

9. Reinhardt proposed the NOMEN NOVUM, *Silus ascanii*, to replace *Salmo silus*, a name which he considered untenable. Under the present rules of nomenclature, the earlier name is acceptable.

10. Costa proposed the NOMEN NOVUM *Goniosoma argentinum* to replace *Argentina sphyraena*, a name which he considered untenable. Under the present rules of nomenclature the earlier name is acceptable. See Cohen (14: 105) for comments on the early history of the name *Argentina*.

Acantholepis Krøyer, Danmarks Fiske, 3 (1), 1846: 97; type species by monotypy, *Salmo silus* Ascanius 1775. Bergen, Norway.

Characters. Maxillaries separated medially by a distance at least one-half the width of the broad underlying mesethmoid (Fig. 3, left). Premaxillary simple, not articulating with the medial portion of each maxillary. Maxillary not enlarged into a knob medially. Distal to the median end, the maxillary sends down a single prong (not shown in figure) which articulates with the posterior face of each premaxillary. Premaxillary without ascending prongs articulating with maxillary. Palatine and vomerine dentition in a rather regular, continuous arch of small, closely spaced, posteriorly directed teeth (Fig. 1, left). Vomerine teeth located less than the length of a tooth behind head of vomer. Recurved tongue teeth present along the lateral edges of the bone as well as at the anterior margin (Fig. 2, left).

Key to Western North Atlantic Species of *Argentina*

- 1 a. Branchiostegal rays 6; scales with spines; lateral-line scales 67 (64–69); gill rakers on lower arm of first arch 13 (11–15). *silus* (Ascanius) 1775, below.
- 1 b. Branchiostegal rays 5; scales without spines; lateral-line scales 51 (49–52); gill rakers on lower arm of first arch 6. *striata* Goode and Bean 1895, p. 13.

Argentina silus (Ascanius) 1775

Atlantic Argentine, Herring Smelt

Figure 4

Study Material. A total of 64 specimens as follows: 20 from Norway, at Lofoten' county Nordland; Askvold and Lysterfjord, county Sogn og Fjordane; W. Salhaus' Gannsfjord, and Baasfjord, county Rogaland; all in BNM. 2 from MICHAEL SARS St. 323 in the Skagerrak, BNM. 9 from off Scotland, 58°46.5'N, 3°52'E, and 58°25'N, 5°00'E, SU. 1 from south of Ireland, 50°57'N, 10°46'W, BNM. 3 from the Atlantic coast of Canada, one of these from 48°N, 63°10'W, ROMZ. 28 from off Nova Scotia, 43°18'N, 64°14'W; 43°39'N, 59°08'W; and 42°41'N, 64°13'W; 27 of these, from the first two localities, at SU, and 1, from the last locality, MCZ. One specimen from Massachusetts Bay, also MCZ.

Distinctive Characters. The presence of spiny scales and six branchiostegal rays separates *A. silus* from all other argentinids except *A. sphyraena*. It differs from *sphyraena*, and from other argentinids as well, in having a high lateral-line count, 67 (64–69), and a high vertebral count, 65–67.

Description. Proportional dimensions in per cent of standard length, based on 59 specimens from Europe and North America, ranging from 77.4 to 321.9 mm SL. The average is followed by the range in parentheses.

Body: depth at dorsal fin 16.1 (11.3–22.0); width behind head 11.9 (9.3–14.7).

Caudal peduncle: least depth 6.5 (6.0–7.6).

Head: length 27.5 (25.4–29.6); depth 14.3 (12.7–15.5).

Snout: length in front of eye 7.9 (7.0–8.8).

Eyes: horizontal diameter 9.0 (6.0–11.1); distance between 7.5 (6.5–8.3).

Maxillary: length 6.2 (5.2–7.4); greatest depth 1.8 (1.5–2.2).

Distance from tip of snout to: origin of anal fin 82.4 (79.8–85.4); origin of dorsal fin 43.1 (40.7–45.4); base of

ventral fin 52.5 (50.0–55.4); base of pectoral fin 27.3 (24.6–30.1).

Lateral-line scales: 66 (64–69).

Branchiostegal rays: 6.

Gill rakers: on first arch 6 (5–7) + 1 + 13 (11–15).

Fin rays: dorsal 12 (11–13); anal 15 (11–17); pectoral 17 (15–18); ventral 12 (12–13).

Vertebrae: 67 (two specimens from the western Atlantic); 65 (one specimen from the eastern Atlantic).

Pyloric caeca: 21, 22, 28 (three specimens from the western Atlantic); 15, 27 (two specimens from the eastern Atlantic).

Body slender to robust, laterally compressed; deepest at dorsal origin; gravid females with bellies much distended; dorsal profile curving gently to snout from point of greatest depth and extending in a straight line from that point to caudal peduncle. Scales distinguished by small but strong spines, easily discernible by running a finger forward along the side of a specimen; spines often growing from posterior margin of scale as well as from lateral surface, thus imparting a distinctly ctenoid appearance. As in many other species of *Argentina* and *Glossanodon*, the scales mold the body into an elongated, angular box, at least in adolescents and young adults.

Head with the general shape that of a rather blunt four-sided wedge with the apex at the snout. A distinct knob at the symphysis of mandibles. Eye projecting into dorsal profile of head quite markedly in larger specimens, less so in smaller ones. Adipose eyelid usually not easily discernible except in fresh specimens; the posterior lid continuously connected with a layer of hyaline tissue over the preopercle. Pupil elliptical. Interorbital, between supraocular canals, a broad, flat-bottomed space. Canals raised above surface of median portion of interorbital space. Lateral to canals, frontals arch upward to accommodate the dorsal edges of the large eyes. Gill rakers medium-sized, widely spaced, roughly triangular in shape, and compressed; the 4th raker forward from angle on lower arm of first arch equal to approximately 0.25 of the interorbital width; rakers on upper arm fewer in number and slightly smaller than those on lower arm.

Jaws subequal, the upper jaw rounded, the lower jaw rather bluntly pointed. Maxillary with its dorsal edge fitting under the lachrymal and extending to the jugal as well, its posterior edge closer to eye than to tip of snout. The epidermis covering the ventral edge of maxillary bearing a considerable number of small papillae, visible to

the naked eye in many larger specimens; these papillae, much reduced in size, extending in a narrow band onto the epidermis covering the premaxillary, there meeting a similar band from the other side.

Teeth in bands 1-3 teeth wide on palatines and on vomer; about 25 teeth on each palatine, about 18 on the head of vomer. Tongue armed with 8-10 strong recurved teeth; minute, broad-based papillae with 1-5 short twig-like branches on each (similar to those on epidermis of maxillary and premaxillary), thickly distributed along margins of tongue and interspersed between teeth. Similar papillae in large numbers on ridges on floor and roof of the pharynx. Dentaries in the only two larvae examined by me



FIGURE 4. *Argentina silus*, female, 436 mm SL, from Scandinavia, and scale from first row below lateral line. From Smitt (47).

(25 and 35 mm TL) bearing a single row of minute cardiform teeth; lower jaw of the next smallest specimen available (71 mm TL) lacking teeth, as in all larger specimens. Ceratobranchial of fifth gill arch bearing 5 small teeth. At anterior end of fourth supra-branchial, two small patches of teeth, about 10 on the posterior patch and 3 on the anterior one.

Dorsal with longest ray approximately equal to depth of body at origin of dorsal fin. Anal rays broken on all specimens seen by me. Pectoral fin originating close to a vertical from posterior edge of opercle, its tip extending to a point about midway between the anterior part of pectoral and ventral fin bases, the posterior end of its base forming an angle of 30-35° with a plane parallel to the venter, the distance between the base of the innermost ray of each fin less than the least depth of the caudal peduncle. Ventral adipose fin anterior to anus noted in two small specimens (54.6 and 63.0 mm SL). Ventral fin slightly shorter than pectoral fin.

Stomach running posteriorly to a point slightly anterior to insertion of ventral fins, the outer surface of its posterior curve bearing an extension which Kendall and

Crawford¹¹ (29: 10) have illustrated and compared to a short caecum. Intestine twisted into a single loop at a point slightly behind a vertical from the posterior tip of stomach; distal to the loop the intestine runs straight back to the anus.

Swim bladder elongated, fusiform, its walls heavily impregnated with a brilliant silvery pigment; its anterior end slightly behind anterior end of body cavity.

Color. Preserved specimens pale on ventral half of body, the dorsal half more heavily pigmented; many with a rich orange-brown color along dorsum and on belly due to countless small oil droplets in the skin beneath the scales. Some Norwegian specimens collected earlier than those described above and probably preserved initially in alcohol have a broad silvery band running the length of body, its dorsal edge slightly above the lateral line and its ventral edge about 0.67 of the distance between lateral line and venter. Caudal fin rather heavily pigmented at its base, less so at the extremities of rays. Dorsal and anal fins lightly pigmented. Pectoral and ventral fins with pigment on their lateral rays only, the median portion of each fin uncolored. Opercle a bright silver color. Cheeks about the same color as ventral half of fish. Top of head transparent posteriorly and translucent farther forward. Muzzle generally dusky, and entire underside of head lightly sprinkled with chromatophores. Adolescent specimens with 10–12 faint, dusky blotches along dorsal half of each side of the body. Peritoneum having outer surface coated with a silvery pigment, the ventral and lateral faces of its inner surface so densely punctate as to appear dark brown or blackish; dorsal surface with fewer chromatophores. Swim bladder visible through peritoneal membranes.

Size. The largest specimen I have examined is 321.9 mm SL; however, this species may reach two Swedish feet or 59 cm (47: 914).

Development. The eggs, 3 to 3.5 mm in diameter, have a prominent flattened oil globule and a vesicular yolk. The colorless, newly hatched larvae are 6 to 9 mm in length and have a large yolk sac, but this is much reduced by the time the fish reach about 12 mm. At this size the mouth is completely open. By 17 mm a characteristic row of pigment spots is present along the belly. At 45 mm the fin rays have formed, the anus has moved forward, and the tail is distinctly forked. The ventral fins become apparent at about 50 mm. Adolescent specimens have 10 to 12 faint, dusky blotches along the dorsal half of each side of the body.¹²

A. silus off the coast of Iceland was found to be relatively slow-growing after the first several years, with sexual maturity occurring between 8 and 15 years of age. The oldest, but not the largest, specimen was 24 years old and had a standard length of 51.0 cm (21: 72–78).

Habits. Spawning off Iceland has been estimated as occurring in April and May (21: 72–78). In the eastern Atlantic, eggs have been taken between May and September,¹³ in the Gulf of Maine during April (7: 140).

11. Kendall and Crawford have reported a "functional spiral valve" in *A. silus*. I have dissected the intestines of six specimens of *A. silus*, four from the western Atlantic and two from the eastern Atlantic, and in none of these was I able to confirm the observations of these authors. Instead I noted 23 spiral rings. See Cohen (14: 96) for further comments on the "spiral valve" in bony fishes, and for additional references.

12. See Schmidt (43: 1–16) for figures and detailed descriptions of development in *A. silus* and results of experiments on the relative density and depth distribution of eggs.

A. silus has been caught on hook-and-line close to shore, but this is a rare event. It is probably the deepest-living and most oceanic member of the genus, having been consistently taken at greater depths and at greater distances from shore than any other *Argentina*. On the American side of the Atlantic it has been caught at depths as great as 380 fathoms (45: 370), although it is most commonly encountered between 75 and 120 fathoms. The deepest recorded occurrence of *A. silus*, off Norway, is 500 fathoms (17: 167), but other Scandinavian and British records range from 50 to 200 fathoms. Icelandic records range from 120 to 1100 m (21: 72-78). Eggs in the northeastern Atlantic are pelagic at depths to 900 m, with the greatest concentrations between 300 and 400 m. They are most commonly encountered in the area over the 1000-m curve.¹²

Although *A. silus* is not a commercially important species, it is not a rare fish in the catches of the otter trawlers. Most catches are probably made close to the bottom. This species evidently occurs in aggregations, as single specimens are rarely caught. During recent investigations (45: 370), *A. silus* was taken most commonly in groups of 11 to 100. One catch of 15,000 pounds (19: 11) and another of 1000 individuals (R. C. Wilson, in litt.) have been noted.

Analysis of the catch records from an expedition in Icelandic waters (30: 169-191) shows that at each of the 16 stations at which *A. silus* was trawled, *Sebastes marinus* was also taken. *Molva byrkelange*, *Brosme brosme*, and *Sebastes viviparus* were caught with it in more than half of the hauls; *Lepidorhombus whiffiagonis* and *Hippoglossoides platessoides* were present with *A. silus* half of the time.

Little is known of its food. I have found partially digested shrimp-like crustaceans in the guts of several American specimens; the bathypelagic fish *Cyclothone braueri* has been taken from the gut of one from Denmark Strait (30: 169-191).

A correspondingly sparse amount of information is available on predators of *A. silus*. There is one report of it taken from the gut of *Sebastes* (30: 169-191) and of another from the gut of *Phycis tenuis*? (23: 261).

Relationships. *A. silus* is a quite distinct species; its two closest relatives are *A. sphyraena* of the eastern Atlantic and *A. sialis* from off the Californias. The geographical ranges of *silus* and *sphyraena* overlap to a considerable extent; however, *silus* has its center of distribution in deeper water, and there seems to be no evidence of interbreeding between the two. Although *A. sialis* resembles *silus* in its high gill-raker count, silvery swim bladder, and general appearance, it is at once distinguished from *silus* by the absence of spines on the scales, a lower lateral-line count, and in various other ways.

The examples of *A. silus* which I have examined from each side of the Atlantic have been remarkably constant for the characters investigated. I noted only three proportional differences based on percentages of standard length, and these overlap to a considerable extent; the first set of data gives the mean, with ranges in parentheses, for the American specimens followed by comparable data for the European specimens: head length 28.0 (26.3-29.6), 26.8 (25.4-28.9); eye 9.3 (8.0-11.1), 8.7 (6.0-9.7); interorbital 7.7 (7.1-8.3), 7.2 (6.7-7.9).

Relation to Man. *A. silus* has never been taken consistently in quantities sufficient to make it the object of a commercial fishery. Any catches by fishermen are incidental to the quest for other species. It remains to be seen whether or not *A. silus* plays a significant role in the economy of any commercial fish.

Range. *A. silus* has a disjunct distribution, with populations on each side of the North Atlantic. Its southern limit on the American side seems to be the edge of Georges Bank east of Cape Cod. It has been taken in the Gulf of Maine,¹³ up the southeast coast of Nova Scotia, in the Gulf of St. Lawrence, on St. Pierre Bank, and on the southwestern edge of the Grand Bank. The most northerly record for the species is 54°38'N, 53°38'W, east of Hamilton Inlet, Labrador (H. J. Squires, in litt.).

The European population has its southernmost record at about 49°N, south of Ireland. From this latitude it ranges along the west coast of the British Isles and into the Irish Sea. It occurs northwestward to the Faeroes and is known from Iceland and from several localities in Denmark Strait not far from the west coast of Greenland; however, the Greenland records may indicate strays rather than a permanent population. Along the west coast of continental Europe, *A. silus* has been taken at Blaavands Huk on the west coast of Denmark, in the Skagerrak, along the coast of Norway to North Cape; also at Bear Island and near the southeastern coast of Spitsbergen in the Arctic Ocean.¹⁴

Synonyms and References:

Salmo silus Ascanius, Icon. Rerum Natur. Copenh., 3, 1775: 3, pl. 24 (orig. descr.; Bergen, Norway).

Coregonus silus Cuvier, Règne Anim., 2, 1817: 163 (listed).

Silus ascanii Reinhardt, Bemärk. Skand. Ichthyol., 1833: 11 (NOMEN NOVUM PRO *Salmo silus* Ascanius).

Argentina silus Risberg, Observ. Ichthyol., 1835: 3 (descr., synonym., Bergen, Söndmör, Christiana, Norway, common names; not seen); Goode and Bean, Smithson. Contr. Knowl., 30, 1895: 52, fig. 61 (descr., synonym., Sable I. Bank, 200 fms., Belfast and Biddeford Pool, Maine); Jordan and Evermann, Bull. U.S. nat. Mus., 47 (1), 1896: 526, fig. 232 (descr., distr.); Garman, Mem. Mus. comp. Zool. Harvard, 24, 1899: 403 (listed); Kendall, Occ. Pap. Boston Soc. nat. Hist., 7 (8), 1908: 49 (listed); Kendall, Proc. Portland Soc. nat. Hist., 3 (1), 1914: 39 (Maine records); Kendall and Crawford, J. Wash. Acad. Sci., 12, 1922: 8, figs. 1-2 (osteol., soft anat., N. Amer. records, relations.); Bigelow and Welsh, Bull. U.S. Bur. Fish. (1924), 40 (1), 1925: 147, fig. 59 (descr., distr., Gulf of Maine records, habits); Jordan, Evermann, and Clark, Rep. U.S. Comm. Fish. (1928), 2, 1930: 68 (synonym., listed); Firth, Bull. Boston Soc. nat. Hist., 61, 1931: 10 (e. N. Atlant. records); Vladikov and McKenzie, Proc. N.S. Inst. Sci., 19 (1), 1935: 59, fig. 57 (listed); Bigelow and Schroeder, Bull. U.S. Bur. Fish., 48 (20), 1936: 328 (off Georges Bank and Cape Cod, in deep water); McKenzie and Homans, Proc. N.S. Inst. Sci., 19 (3), 1937: 277 (43°05'N, 62°35'W, off Nova Scotia, 54 fms.); McKenzie, Proc. N.S. Inst. Sci., 20 (1), 1939: 15 (W. to SW. of Emerald Bank, Nova Scotia); Breder, Field Bk. Mar. Fish. Atlant. Coast, 1948: 75, fig. (Amer. distr., spawn., eggs); Bigelow and Schroeder, Fish. Bull. (74) U.S. Fish Wildl. Serv., 53, 1953: 139, fig. 59 (descr., eggs, larvae, distr., Gulf of Maine); Anon., Comm. Fish. Rev., 17 (7), 1955: 35 (1000-pound catch at edge of continental shelf, New England); Schroeder, Deep-sea Res., 3, Suppl., 1955: 362 (off Nova Scotia over 200 fms.); Cohen, Bull. Florida State Mus., Biol. Sci., 3 (3), 1958: 117 (synonym., descr., distr., habits, nomencl., gives European refs. not given here).

Acantholepis silus Krøyer, Danmarks Fiske, 3 (1), 1846: 97, fig. (descr., synonym., nomencl., distr., common names).

Argentina syrtensium Goode and Bean, Proc. U.S. nat. Mus. (1878), 1, 1879: 261 (orig. descr.; from stomach

13. See Bigelow and Schroeder (7: 140) for more detailed locations in the Gulf of Maine.

14. See Schmidt (44: 9) for records of postlarval *A. silus* off Great Britain and Iceland. Kotthaus and Krefft (30: 171) have given a number of localities near Iceland and in Denmark Strait, while Andriashev (1: 119) summarized far northern records. Smitt (47: 913) has given Scandinavian records.

of hake [*Phycis tenuis* ♀] in 200 fms. on Sable I. Bank off Nova Scotia, type USNM 21624; Jordan and Gilbert, Bull. U.S. nat. Mus., 16, 1883: 295 (descr.); Jordan, Rep. U.S. Comm. Fish. (1885), 13, 1887: 830 (listed).

Negative References:

Argentina silus Murray and Hjort, Depths of Ocean, 1912: 394, fig. 261 [26°03'N, 15°00'W; equals *Glossanodon leioglossus* (Valenciennes) 1848; fig. is *A. silus* after Smitt, Skand. Fisk., ed. 2, 2, 1895: 913]; Fowler, Bull. Amer. Mus. nat. Hist., 70 (1), 1936: 196, fig. 84 (listed, after Murray and Hjort; fig. is *A. silus* after Goode and Bean, Smithson. Contr. Knowl., 30, 1895: fig. 61).

Argentina striata Goode and Bean 1895

Figures 3, 5

Study Material. A total of 122 specimens as follows: 29 from the Atlantic coast of North America between Virginia and Florida, SU, MCZ, and SAFI collections; 66 from the Gulf of Mexico off Yucatán, Texas, Louisiana, Alabama, and Florida, including Dry Tortugas, CNHM, FSM, and SU; 1 from off Honduras, USNM; 26 from off Venezuela, FSM and USNM.

Distinctive Characters. *A. striata* differs from other North Atlantic *Argentina* in lacking spines on its scales and in not having silvery pigment on the swim bladder. It has six gill rakers on the lower arm of the first gill arch, less than any other *Argentina* except the western Pacific *A. elongata*, from which *striata* differs in having 18 to 20 pectoral rays (13 to 17 in *elongata*) and about 45 vomerine teeth (about 25 in *elongata*).

Description. Proportional dimensions in per cent of standard length, based on 42 specimens from the western North Atlantic, ranging in size from 98.6 to 185.6 mm SL. The average is followed by the range in parentheses.

Body: depth at dorsal fin 12.8 (11.7–15.3); width behind head 11.3 (10.2–12.4).

Caudal peduncle: least depth 6.0 (5.5–6.8).

Head: length 30.0 (26.1–34.3); greatest depth 13.0 (12.0–14.9).

Snout: length in front of eye 9.9 (8.5–11.1).

Eyes: horizontal diameter 9.4 (7.3–11.0); distance between 7.9 (6.9–8.9).

Maxillary: length 5.5 (4.9–6.3); greatest depth 1.7 (1.3–2.0).

Distance from tip of snout to: origin

of anal fin 84.1 (81.6–86.5); origin of dorsal fin 47.3 (43.8–51.8); base of ventral fin 55.0 (50.3–58.3); base of pectoral fin 29.2 (26.8–33.0).

Lateral-line scale pockets: 51 (49–52).

Branchiostegal rays: 5.

Gill rakers: on first arch 3 (3–4) + 1 + 6.

Fin rays: dorsal 11 (11–12); anal 13 (12–14); pectoral 19 (18–20); ventral 12 (11–13).

Vertebrae: 49 (three specimens).

Pyloric caeca: 9 (three specimens).

A rather slender species, slightly compressed laterally between the head and dorsal base, more so from that point posteriorly, the greatest body depth between head and

dorsal origin. Scales evidently very deciduous. I have seen no specimens with complete squamation, and the few scattered scales examined by me are thin and lack spines.

Head with dorsal profile descending in a gentle curve from eye to snout; its ventral profile rising to snout in an almost unbroken curve, with only a very slight inflection at the union of the articular and quadrate. A reduced symphysial knob sometimes present. Eye projecting slightly into dorsal profile of head. Pupil elliptical. Interorbital broad and flat between supraocular canals, which are slightly above the medial area. Lateral to the canals, the frontals are raised still farther to accommodate the top of eye. Gill rakers on lower arm of first arch medium-sized, widely spaced, triangular in shape, and compressed; the base of each raker's edge bearing a fleshy pad; the 4th raker



FIGURE 5. *Argentina striata*, 128 mm SL, southeast of Trinidad, OREGON St. 1989, 9°45'N, 59°45'W, USNM 159357. Drawn by Miriam Wilson.

forward from angle equaling slightly more than one-sixth of the interorbital distance, 3 or 4 rakers on upper arm decreasing in size from the angle forward, and much reduced.

Upper and lower jaws rounded, the upper jaw projecting slightly. Maxillary with dorsal edge under lachrymal but not extending to jugal; its posterior edge slightly closer to eye than to snout. Extremely minute papillae on the membrane covering the maxillaries and premaxillaries of most specimens, but apparently absent in several.

Teeth on palatines and on head of vomer in a continuous band; small, closely spaced, and posteriorly directed; the bands varying in width from 1 to 3 teeth on palatines to 4 or 5 teeth on vomer; about 35 teeth on each palatine, about 45 on the vomer. Tongue bearing 5-9 strong, recurved teeth. Sensory papillae not observed on tongue, but many of the fishes examined had small, hemispherical protuberances clustered along its tooth-bearing areas. Ceratobranchial of fifth gill arch bearing 18 small, conical teeth. Anterior end of fourth suprabranchial with two patches of short, conical teeth, about 11 teeth in the anterior patch, 17 in the posterior patch.

Dorsal with the longest ray equal to approximately the greatest depth of body. Anal's longest ray equal to distance between bases of outermost rays of ventral fins. Pectoral fin usually originating on, ahead of, or slightly behind, a vertical from posterior tip of opercles, its tip extending to a point less than 0.5 the distance between an-

terior bases of pectoral and ventral fins, the posterior end of its base forming an angle of 40–60° with a plane parallel to the venter, the distance between the bases of the innermost pectoral rays slightly less than the least depth of the caudal peduncle. Ventral fin about equal in length to pectoral fin.

Stomach extending forward to a point slightly anterior to posterior tip of pectorals before turning downward; the outer curve smooth. Pyloric caeca extending to a point between anterior and posterior curves of stomach. Intestine, distal to caecal section of the gut, extending straight back to the anus as a narrow, thin-walled, transparent tube.

Swim bladder lacking silvery pigment, but with an iridescent sheen in many.

Color. In preserved specimens, ventral half of body light brown; a band of lighter brown, along the lateral line, bordered on its dorsal edge by a narrow dark brown band; entire dorsum of body brown. Skin of some specimens reflecting an iridescent sheen, and a few examples with remnants of what must have been a broad silvery band running the length of the body, with the lateral line as a dorsal border. Fins all lightly flecked with brown except for the unpigmented median half of the pectorals. Opercles of some specimens bright silver, as are the cheeks; others with silver pigment dissolved and opercle transparent with chromatophores sprinkled near the bottom but rather thickly concentrated near the top. Top of head transparent posteriorly and translucent farther forward. The muzzle, from nostrils forward, dusky. Peritoneum with its outer surface silvery, the dorsal half of its inner surface lightly colored by large, relatively widely dispersed chromatophores, these more closely crowded together on ventral half of body cavity, giving this area a much darker appearance. Gut immaculate.

Size. The largest specimen on record is 190 mm (31: 14).

Development. Nothing is known of the eggs or early life history of *A. striata*. I have examined a 35-mm juvenile and find a very distinctive body color pattern consisting of 11 transverse stripes, one on the opercle, and another across the caudal fin. None of the stripes is continuous over the dorsum, but the last seven body stripes are continuous around the venter. The ventral fins are strongly pigmented, the bases of the pectorals less so.

Habits. *A. striata* has been captured at depths ranging from 52 to 250 fathoms, although it is most frequently taken between 100 and 200 fathoms, and most often over a mud bottom. Most Gulf of Mexico specimens have been taken in shrimp trawls.

Although *A. striata* has long been known from only a few specimens, recent fishery investigations in the western North Atlantic indicate that the species is not rare in mud bottom habitats of proper depth (48: 2; F. H. Berry, personal communication). Specimens are encountered more often in aggregations of two to ten than singly.

Analysis of data on shrimp-trawl catches in the Gulf of Mexico (48: 2) indicates that there are no fish species with which *A. striata* is invariably associated in the trawls; however, it was taken with species of *Bembrops* in over half of the hauls and with *Peristedion miniatum* 40% of the time. *Polymixia lowei* and species of *Merluccius* and of *Chlorophthalmus* were present in about 33% of the catches that included *A. striata*; *Paralichthys squamilentus*, *Pontinus longispinus*, *Saurida normani*, *Coelo-*

rhynchus caribbaeus, *Malacocephalus occidentalis*, and species of *Antigonia* were present about 20% of the time.

The stomach of a single specimen, taken northwest of Dry Tortugas, contained sponge remains and calcareous skeletons of protozoans.

Relationships. *A. striata* is closely related to the western Pacific *Argentina elongata* but differs mainly in having more vomerine teeth and more pectoral fin rays.

Relation to Man. Nothing is known of its relation to man; however, a closely related form, *Argentina elongata australiae*, is a forage fish for commercial species taken in the southeast Australian trawl fishery (18: 125).

Range. *A. striata* is evidently widespread along the continental shelf of the western Atlantic where proper ecological conditions prevail. It has been taken from the offing of southeastern Nova Scotia (45: 362) to the east coast of Florida (14: 132), in the Gulf of Mexico off Florida, Alabama, Louisiana, Texas, Yucatán Peninsula, and in Campeche Bay (48), from the Caribbean off Honduras, along the Atlantic coast of Venezuela southeast of Trinidad, and off Ilha de São Sebastião, Brazil.

References:

Argentina striata Goode and Bean, Smithson. Contr. Knowl., 30, 1895: 52, fig. 62 (orig. descr.; 28°36'N, 85°33'W, Gulf of Mexico, 111 fms.; type, USNM 48263); Jordan and Evermann, Bull. U.S. nat. Mus., 47 (1), 1896: 526 (descr.); Garman, Mem. Mus. comp. Zool. Harvard, 24, 1899: 403 (listed); Jordan, Evermann, and Clark, Rep. U.S. Comm. Fish. (1928), 2, 1930: 68 (listed); Longley and Hildebrand, Publ. Carnegie Instn. Wash., 535, 1941: 14 (Dry Tortugas, Florida, 160–197 fms.); Schroeder, Deep-sea Res., 3, Suppl., 1955: 362 (offing of se. Nova Scotia to offing of Cape Charles, Virginia, less than 200 fms.); Springer and Bullis, Spec. Sci. Rep.-Fish., U.S. Fish Wildl. Serv., 196, 1956: 49 (locals., Gulf of Mexico); Cohen, Bull. Florida State Mus., Biol. Sci., 3 (3), 1958: 117 (refs., descr., distr., habits); Miranda Ribeiro, Bol. Mus. Nac., Rio de J., N.S. 224, 1961: 3, fig. 1 (5 specimens, 24°14'S, 44°49'W).

Genus *Glossanodon* Guichenot 1867

Glossanodon Guichenot, Ann. Soc. linn. Dép. Maine-et-Loire, 9, 1867: 7; type species by original designation, *Argentina leioglossa* Valenciennes 1848. Alger, Algeria.

Characters. Maxillaries in contact medially or separated by a narrow space less than one-fourth of the width of the narrow underlying mesethmoid (Fig. 3, right). Medial portion of maxillary enlarged in some species. Distal to the median line, the maxillary sends down a prong (not shown in Fig. 3, right) which articulates with the posterior face of a prong sent up by the premaxillary. Vomerine dentition an irregular row of small, conical teeth across the head of the bone, but set back from the anterior edge a distance equal to three or more times the length of a tooth (Fig. 1, right). Palatine and vomerine teeth easily distinguished, as an area of unossified cartilage generally separates the two bones. Palatine dentition various. Tongue teeth, when present, only at the anterior end of the tongue, absent along the lateral edges (Fig. 2, right). Body slightly laterally compressed anteriorly, more so posteriorly. A slight but distinct knob usually present below the symphysis of the dentaries. Posterior tip of maxillary closer to eye than to snout. As far as known, the scales lack spines.

Key to Western North Atlantic Species of *Glossanodon*¹⁵

- 1 a. Distance from vent to anterior end of anal fin base equal to or less than half the depth of caudal peduncle; lateral-line scales 48–50; pectoral rays 19–22; dentary teeth present in adults; palatine not divided in two parts.
polli Cohen 1958, below.
- 1 b. Distance from vent to anterior end of anal fin base equal to or greater than the depth of the caudal peduncle; lateral-line scales 43–46; pectoral rays 12–14; dentary teeth absent in adults; palatine divided into an anterior plate and a more elongated posterior portion.
pygmaeus Cohen 1958, p. 19.

Glossanodon polli Cohen 1958

Figure 6

Study Material. A total of 10 specimens: 6, including the type, from the tropical eastern Atlantic, five in MRCB, and one, a paratype, in SU; 4 from off Brazil, USNM (two of these, previously unrecorded, from 2°41'N, 47°48'W).

Distinctive Characters. In *G. polli*, the dentary teeth extend all the way to the symphysis, a feature that distinguishes it from its nearest relatives, *G. leioglossus* and *semifasciatus*. The vent is close to the anterior end of the anal fin and the palatine bone is not in two parts.

Description. Proportional dimensions in per cent of standard length, based on four specimens from off Brazil, ranging in size from 74.3 to 140.5 mm SL. The average followed by the range in parentheses.

Body: depth at dorsal fin 9.9 (8.8–11.0); width behind head 9.1 (9.1–9.3).

Caudal peduncle: least depth 5.9 (5.5–6.1).

Head: length 28.4 (26.6–30.4); greatest depth 8.7 (7.4–10.9).

Snout: length in front of eye 9.6 (8.9–9.9).

Eyes: horizontal diameter 8.9 (7.0–9.6).

Maxillary: length 7.4 (6.9–8.0); greatest depth 3.4 (2.5–4.2).

Distance from tip of snout to: origin of anal fin 83.2 (82.3–84.8); origin of dorsal fin 47.4 (45.0–50.4); base of ventral fin 52.3 (50.2–55.2).

Lateral-line scale pockets: about 50.

Branchiostegal rays: 5.

Gill rakers: on first arch 10+1+20–23.

Fin rays: dorsal 12; anal 11–12; pectoral 21–22; ventral 11–12.

15. The key characters noted above not only separate *G. pygmaeus* from *G. polli* but also sharply delimit *pygmaeus* from all other species in the genus. For these reasons, Cohen (14: 155) has proposed the subgenus *Prosoarchus* for *G. pygmaeus*.

Body slender, tapering to the caudal peduncle, the greatest depth behind head. Distance from vent to anterior edge of anal fin base 0.5 of the least depth of caudal peduncle, or less.

Head with dorsal profile not interrupted by dorsal rim of eye, its ventral profile rising in a gentle curve from posterior edge of preopercle to the union of articular and quadrate, thence in a straight line to the tip of the slightly projecting lower jaw. Adipose eyelid present. Pupil elliptical. A patch of white tissue overlies posterodorsal segment of iris. Interorbital space between supraocular canals a broad, flat-bottomed

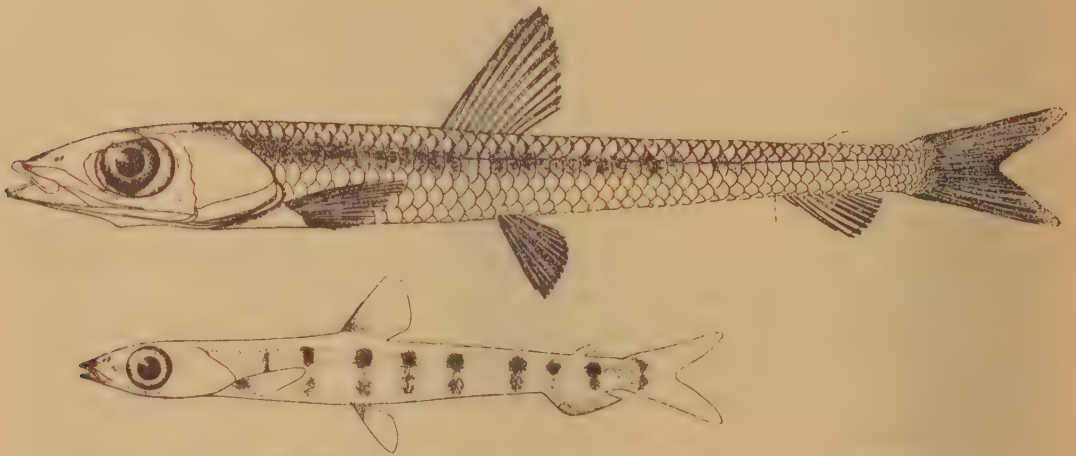


FIGURE 6. *Glossanodon polli*. Off French Guinea, $9^{\circ}31'30''$ N, $16^{\circ}23'$ W, 150–200 m, MRCB. TOP, 140-mm specimen. BOTTOM, 83-mm specimen, showing juvenile color pattern. From Poll (36).

area, lower than the canals. Frontals, lateral to the canals, sloping downward over the relatively small orbit. Gill rakers elongated and closely spaced; the 4th raker forward from angle on lower arm of first arch equaling 0.33–0.5 of interorbital distance.

Upper and lower jaws rounded. Maxillary with dorsal edge under lachrymal and extending to the joint between lachrymal and jugal. Minute papillae on the epidermis covering ventral edge of maxillary and premaxillary.

Each palatine with 20–35 teeth, short and conical, restricted to lateral edge of bone in several specimens but scattered about surface or in a row along medial edge of bone in others; vomer bearing a patch of 20–25 similar teeth across its head. Lingual teeth apparently absent. Each dentary with 10–20 short conical teeth in a single row on its inner face, extending from angle of gape past midpoint of dentary and usually to symphysis. Branchial arches not examined for teeth.

Pectoral fin with the posterior end of its base forming an angle of 45° – 60° , its tip extending to a point about 67% of the distance between the front of the pectoral and ventral fin bases. Ventral fin slightly shorter than pectoral fin.

Swim bladder without silvery pigment.

Color. Body of a preserved specimen, light tan. A dark brown streak, equal in width to diameter of pupil, extending along dorsolateral contour of body; 8 or 9 more densely pigmented areas along the band, these more pronounced in smaller specimens. An iridescent band, below and equal in width to the dark brown stripe, running along lateral line. Some of the scale pockets along dorsum edged with brown. Muzzle dusky; inner surface of braincase appearing dark brown through the transparent frontals and parietals. Isthmus, opercles, cheeks, and irises bright silver. The postlarval pattern consisting of nine dark transverse streaks along the side of body. Peritoneum silvery on outer surface; its inner surface densely punctate with dark brown chromatophores at anterior end of body, more lightly colored posteriorly. Stomach appears to lack pigment.

Size. The largest specimen known is 140.5 mm SL.

Development. Other than the changes in color pattern with age, nothing is known of development.

Habits. The known bathymetric range in the eastern Atlantic is 150 to 200 m. One collection was made over a sand bottom, the other over sand and rock. Larger specimens caught off French Guinea in June were sexually mature or almost so (36: 53). Western Atlantic specimens have been taken at 175 to 225 fathoms over a mud bottom with a 40-foot shrimp trawl.

Stomachs of eastern Atlantic specimens contained crustaceans (36: 53).

Relationships. *G. polli*, closely related to *G. leioglossus* from the Mediterranean and Canary Islands and to *G. semifasciatus* from Japan, differs from both chiefly in having more teeth on the dentary. This is probably a primitive character in this Suborder, in which the trend seems to be toward a reduction of the mouth parts and lower jaw dentition. *G. polli* may well be the most primitive known argentinoid fish.

Range. This species has been collected at three localities by the recent Belgian Oceanographic Expedition along the coast of West Africa; one locality of capture is unknown; the other two are off French Equatorial Africa and off the border of Sierra Leone and French Guinea. In addition, I have examined specimens collected off the Brazilian coast close to the equator. When more material is available from both sides of the Atlantic, subspecific differentiation between the two populations may become apparent.

References:

- Argentina sphyraena* Poll, Résult. Sci. Exped. océanogr. Belge (1948-1949), 4 (2), 1953: 53, fig. 20, non Linnaeus 1758 (descr., habits, 3°05'S, 9°25'E, 9°31'N, 16°23'W).
Glossanodon polli Cohen, Bull. Florida State Mus., Biol. Sci., 3 (3), 1958: 151, fig. 8 (orig. descr.; 1°49'N, 46°48'W, 225 fms.; 1°52'N, 46°54'W, 175 fms.; both off Brazil; also African locals. cited by Poll; type MRCB 95.005).

Glossanodon pygmaeus Cohen 1958

Figure 7

Study Material. A total of 53 specimens: 2 from off South Carolina, USNM; 28 from off Georgia and the east coast of Florida, SAFI and FSM; 1 from Cay Sal

Bank, USNM; 8 from off Dry Tortugas, SU and CNHM (including the type, CNHM 64345); 1 from off Pensacola Bay, Florida, CNHM; 4 from off Louisiana, USNM; 2 from off Port Aransas, Texas, one at CNHM and the other at SU; 1 from the Caribbean side of Nicaragua, USNM; 5 from off Venezuela, three in USNM and two in FSM; 1 from off equatorial Brazil, USNM.

Distinctive Characters. *G. pygmaeus* can be distinguished from all other argentinids by the advanced position of the anus, which is in front of the origin of the anal fin base by a distance equal to or greater than the least depth of the caudal peduncle. *G. pygmaeus* also has a lower pectoral ray count (12 to 14) and a lower lateral-line scale count (43 to 46) than any other *Glossanodon*.

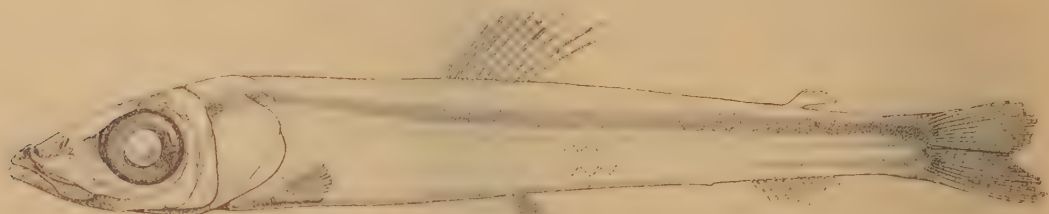


FIGURE 7. *Glossanodon pygmaeus*, 84.5 mm SL, holotype, Gulf of Mexico off Dry Tortugas, 25°08' N, 84°19' W, 163 fathoms, CNHM 64345. From Cohen (14).

Description. Proportional dimensions in per cent of standard length of 14 specimens, counts based on 18 specimens, ranging in size from 52.5 to 98.5 mm SL, from the areas noted above. The average is followed by the range in parentheses.

Body: depth at dorsal fin 12.1 (10.1–14.0); width behind head 10.4 (8.5–11.3).

Caudal peduncle: least depth 6.0 (5.3–6.8).

Head: length 28.7 (27.2–30.0); greatest depth 13.0 (12.0–14.3).

Snout: length in front of eye 9.2 (8.0–10.2).

Eyes: horizontal diameter 8.9 (8.1–9.7); distance between 7.2 (6.1–8.8).

Maxillary: length 8.0 (6.7–8.9); greatest depth 2.8 (2.4–3.3).

Distance from tip of snout to: origin of anal fin 81.5 (80.1–84.8); origin of

dorsal fin 47.6 (45.3–49.6); base of ventral fin 54.2 (51.6–58.7).

Lateral-line scale pockets: 46 (43–46).

Branchiostegal rays: 5 (anterior ray on each side much smaller than others).

Gill rakers: on first arch in four specimens 10 (9–11) + 1 + 22 (21–23).

Fin rays: dorsal 11 (10–12); anal 12 (11–13); pectoral 13 (12–14); ventral 10 (10–12).

Vertebrae: 43 (one specimen).

Pyloric caeca: 8 (two specimens), 9 (one specimen).

A small, slender-bodied species, the body deepest behind head, tapering gradually to the caudal peduncle; even gravid females very slender. Scales cycloid

and thin; evidently very deciduous, only a few scattered scales seen in the specimens examined.

Upper profile of head descending to snout in a very gentle curve, unbroken by dorsal margin of eye in smaller specimens, but orbit may project slightly in larger examples; ventral profile rising gently from posterior edge of preopercle to union of articular and quadrate, thence rising more rapidly. Adipose eyelids weak but discernible in most specimens. Pupil elliptical. A patch of white tissue over posterodorsal segment of iris. Interorbital space between supraorbital canals flat; the canals raised slightly above the central area. The frontals, lateral to the canals, arching upward very slightly. Gill rakers elongated and closely spaced; the 4th raker forward from angle on lower arm of first arch equal in length to about half of the interorbital distance; rakers on upper arm fewer in number and slightly smaller.

Lower jaw projecting slightly in most specimens, but the jaws about equal in several. Maxillary with dorsal edge tucked under lachrymal and jugal. Minute papillae distributed on skin along ventral edge of premaxillary, but apparently lacking on ventral edge of maxillary. The tooth-bearing areas of palatines poorly ossified; the anteriormost portion of the bone a thin, tooth-bearing plate, present in the same body of cartilage as the main body of the ossified palatine but not connected to it by bone. Vomer also poorly ossified, especially in a hemispherical area at the tip.

Teeth on main body of palatine conical, numbering 10–25 in an irregular row, usually single on posterior part of bone and 2 or 3 teeth wide on anterior part; the row continuing onto the anterior plate of palatine with 10–17 teeth in a band 2–4 teeth wide; vomer also bearing a continuation of this band, consisting of 11–18 widely scattered conical teeth. Tongue armed with 2–6 teeth. Ceratobranchial of fifth gill arch bearing 4 small conical teeth. Anterior end of fourth suprabranchial with two oval-shaped patches of short, conical teeth, about 2 teeth on anterior patch and 7 on the posterior one.

Dorsal with its longest ray slightly longer than the greatest depth of body at dorsal's origin. Pectoral fin with tip extending more than half of the distance between anterior ends of pectoral and ventral fin bases, the posterior end of its base forming an angle of 45–50° with the long axis of the fish. Ventral fin shorter than pectoral fin.

The smoothly rounded posterior curve of the stomach extending almost to the level of posterior tip of pectoral fin.

Swim bladder with anterior end above posterior curve of stomach, lacking silvery pigment.

Color. Alcohol specimens with a uniform light tan ground color. In some, a dark brown stripe equal in width to half the interorbital, running along dorsolateral margin of body and continuing onto upper edge of opercle; in others the stripe is reduced to a lightly pigmented band. A faint iridescent sheen along lateral line suggests that a silvery band may have been present here also. Large brown chromatophores sprinkled along lateral line to form a poorly defined band ventral to the one mentioned above.

A similar poorly defined band on ventrolateral contour of body above area between anus and caudal base. Dorsal and ventral areas of pigmentation meeting at caudal base, coloring entire area a light brown. In many specimens, the scale pockets on dorsum and venter are neatly outlined by dark brown chromatophores. Muzzle dusky; rami of lower jaw and ventral third of opercle and preopercle lightly washed with brown. Isthmus darker due to large brown chromatophores. Posterior portion of cranium lightly dotted with very small brown chromatophores, the outlines of brain visible through them. Dorsal fin rays colored by evenly distributed brown chromatophores. Caudal fin also pigmented, but less evenly. Pectoral, ventral, and anal fins pigmented at their bases but not on their distal portions. In a number of specimens, the dorso-lateral stripe has superimposed upon it 8 or 9 poorly defined dusky blotches composed of large, widely spaced chromatophores. Inner surface of peritoneum densely punctate ventrally, appearing almost solid black, but considerably lighter dorsally. Gut unpigmented.

Size. *G. pygmaeus* is evidently a small species; at least it reaches sexual maturity at a small size, for a female 77.2 mm SL had ripe eggs in the ovary and a male 86.6 mm SL had well-developed testes. The largest specimen I have seen is 112.5 mm SL.

Habits. The known bathymetric range is 50 to 250 fathoms, with the most common occurrence between 100 and 200 fathoms. Most specimens have been taken in shrimp trawls over a muddy bottom, although one collection came from over a sand and gravel bottom.

Recent collections by the South Atlantic Fisheries Investigations of the U.S. Fish and Wildlife Service off the east coast of Florida indicate that *G. pygmaeus* is not a rare fish at proper depths, though it apparently does not occur in large aggregations. The largest series I have encountered consisted of 11 specimens taken off Daytona Beach, Florida, but most collections contain only one to three specimens.

G. pygmaeus has been taken a number of times in company with *A. striata*, which it strongly resembles in color pattern. The gut of one specimen contained several copepods.

Relationships. This species is not closely related to any known *Glossanodon*.

Relation to Man. It may play a role as a forage fish but probably does not grow large enough or occur frequently enough to be a commercial species.

Range. *G. pygmaeus* has been taken in the Atlantic off the coasts of South Carolina, Georgia, and Florida, and from Cay Sal Bank between Cuba and Florida; also near Dry Tortugas in the Gulf of Mexico, and along the Gulf coasts of Florida, Louisiana, and Texas. From farther south I have examined examples from the Caribbean off Nicaragua, from off the coast of Venezuela southeast of Trinidad, and from off the coast of Brazil near the equator.

Reference:

Glossanodon (Prosoarchus) pygmaeus Cohen, Bull. Florida State Mus., Biol. Sci., 3 (3), 1958: 156, fig. 9 (orig, descr.; off S. Carolina; Dry Tortugas and Pensacola Bay, Florida; Port Aransas, Texas; Venezuela. SE. of Trinidad; Brazil, near the equator; 52-163 fms. on continental shelf; type CNHM 64345).

Subfamily MICROSTOMATINAE

*Characters.*¹⁶ Body slender, subcylindrical anteriorly, slightly compressed laterally behind dorsal fin; a cross section through the body would appear round or oval. Snout shorter than half the diameter of eye. Nostrils near upper corner of snout; posterior nostril lacking a flap. Branchiostegals 2 to 4. Lateral line originating near dorsal edge of opercle and running straight back beyond caudal peduncle and onto caudal fin; lateral-line scales larger than other scales and more adherent to body. No scale sheaths over folded ventral fins. Pectoral fins inserted on sides of body.

Supratemporals not in contact with parietals and not fused to pterotics. Mesocoracoids absent. Frontals not fused. Anterior circumorbitals not broadly separate from eye. Teeth on palatines, head of vomer, and dentaries; branchial teeth absent or much reduced.

Remarks. The fishes of this group are pelagic in the upper and middle water layers. All known adults have the silvery pigmentation characteristic of many organisms which live in this habitat.

Range. Probably world-wide in tropical and temperate seas; one species ranges to Greenland.

Genera. This subfamily consists of three quite distinct genera, *Nansenia*, *Microstoma*, and *Xenophthalmichthys*. Although a separate family has been proposed for the last (4: 242, 429), Bertelsen (6: 7) has indicated that there is little but the tubular eyes to separate *Xenophthalmichthys* from *Microstoma*.

Key to Genera

1 a. Eyes of adults nontubular.

- 2 a. Adipose fin present; predorsal length less than 60 % of SL; ventral fins inserted behind a vertical from anterior end of dorsal fin base.

Nansenia Jordan and Evermann 1896, below.

- 2 b. Adipose fin absent; predorsal length greater than 60 % of SL; ventral fins inserted ahead of a vertical from anterior end of dorsal fin base.

Microstoma Cuvier 1817, p. 27.

1 b. Eyes of adults tubular.

Xenophthalmichthys Regan 1925, p. 31.

Genus *Nansenia* Jordan and Evermann 1896

Nansenia Jordan and Evermann, Bull. U.S. nat. Mus., 47 (1), 1896: 528; type species by monotypy or by original designation,¹⁷ *Microstomus grønlandicus* Reinhardt 1839. Fiskeness, West Greenland.

16. A number of these characters have not been checked on *Xenophthalmichthys*.

17. The question of whether or not Jordan and Evermann (28) designated type species for their genera and subgenera has been discussed by Follett and Cohen (20: 73-78) in a request for a ruling currently pending before the International Commission on Zoological Nomenclature.

Generic Synonyms:

Bathymacrops Gilchrist, Rep. Fish. Mar. biol. Surv. S. Afr. (1921), Dept. Mines Industr., 2 (Spec. Rep. 3), 1922: 53; type species by monotypy, *Bathymacrops macrolepis* Gilchrist 1922. PICKLE St. 117, 29°54'S, 31°35'E, east of Durban, S. Africa, in 250 fms.

Euproserpa (subg.) Fowler, Proc. Acad. nat. Sci. Philad., 85, 1934: 256; type species by original designation, *Microstoma schmitti* Fowler 1934. ALBATROSS St. D 5445, east coast of Luzon, in 383 fms.

Characters. Predorsal distance less than 60 % of SL. Ventral fins originating behind a vertical from anterior end of dorsal fin base. Dorsal adipose fin present. Eyes non-tubular and directed laterally.

Range. Species of *Nansenia* are known from the north-temperate Pacific, the North Atlantic, the western Mediterranean, and the western half of the Indian Ocean. They have been caught between the surface and about 450 fathoms. As specimens have not been taken with closing nets, the exact depths of capture are unknown. It seems safe to say, however, that these are not fishes which frequent great depths.

Species. *Nansenia* contains seven nominal species. The status of several is in confusion, and a paucity of material precludes the possibility of a badly needed critical study of the genus.¹⁸ At the present time it is not possible to construct an adequate key to the genus. Only a single species is known from our area.

Nansenia groenlandica (Reinhardt) 1839¹⁹

Figure 8

Study Material. Two specimens from the northwestern Atlantic: one in the collection of Vadim Vladykov, the other (from 40°34'N, 64°07'W) in the USNM.

Distinctive Characters. *N. groenlandica* is a relatively elongated species (body height less than 14 % of SL), with the ventral fins inserted ahead of a vertical from the posterior end of the dorsal fin base and with the dorsal fin generally inserted in front of the midpoint of the body. See *Relationships* (p. 26) for features that distinguish it from *N. oblita*.

Description. Based on a single mutilated female²⁰ from the stomach of a *Chiasmodon niger* which was dipped from the surface at 39°10'N, 69°40'W. Measurements in millimeters.

Caudal peduncle: least depth 10.6.

Head: length 44.7.

Snout: length in front of eye 9.6.

Eyes: horizontal diameter 19.5;
distance between 15.0.

Maxillary: length 8.0; greatest
depth 3.6.

Distance from tip of snout to: origin
of dorsal fin 94.5; base of pectoral fin
46.5.

18. Cohen (13: 52) has commented on most of the nominal species and has given data for several.

19. Cohen (13: 55) and a number of earlier authors have erred in citing the date for this species as 1841. As Schmidt (44: 10, 11, 13) pointed out, the original description appeared in 1839 and was then repeated in 1841 (see Synonyms and References for citations of Reinhardt's two papers).

20. Vladykov (52: 4) has stated that this specimen was 245 mm in length. At present it is in two parts.

Gill rakers: on first arch 10+1
+18.

Branchiostegal rays: 3(?).

Fin rays: dorsal 12; pectoral 10-
9;²¹ ventral 11-11.

Vertebrae: 43-44, according to
Schmidt (44).

A slender fish with body subcylindrical in front of dorsal fin, posteriorly more strongly compressed laterally. Lateral line originating above the opercle and running straight back in midline of body, beyond the caudal peduncle and onto caudal fin.

Head with dorsal profile descending from nape to upper jaw in a nearly straight line, broadly interrupted by the large eye; its ventral profile rising more gently. Snout short and rather blunt, the dorsal profile falling steeply at the level of the nostrils. Eyes following the contour of head in being tilted inward anteriorly, thus giving the



FIGURE 8. *Nansenia groenlandica*, 67 mm SL, from between Great Britain and Iceland, 51°00'N, 11°43'W. From Schmidt (44).

fish a partial anterior as well as a lateral field of vision. Pupil horizontally elliptical. Iris bearing a crescent of white tissue over its posterior half. Interorbital space broad and flat, between the weakly developed supraorbital canals. Supraorbital bones, lateral to canals, arching upward to accommodate the dorsal portion of orbit. Nostrils paired, located at anterodorsal angle of snout, apparently lacking flaps. Opercle with posterior margin thin and scale-like, a shallow semicircular concavity along its posterior margin. Gill openings extensive, evidently reaching to dorsal level of the opercle. Branchiostegal rays broad, leaf-like appendages. Gill rakers medium-sized, compressed structures, tapering at the apex, and relatively widely spaced, their bases not closely appressed.

Mouth small, terminal, composed of the scoop-like dentary, the reduced premaxillaries, and the obliquely placed, broad, scale-like maxillary, most of which is covered by the preorbitals. Posterior end of maxillary closer to eye than to end of snout.

Teeth short, conical, in a single row on head of vomer, seemingly continuing onto palatines. Dentary dentition consists of a single row of compressed teeth. Tongue broad and spatulate, lacking teeth.

Dorsal fin slightly longer than postorbital area of head. Dorsal adipose fin over posterior end of anal fin base. Pectoral fins equal in length to diameter of eye, inserted about 33 % of the distance up the side of body at an angle of about 60° from the horizontal. Ventral fins equal in length to pectoral fins.

21. The original description of this species gives 11 for the pectoral fin count, close to that noted above. On the other hand, Schmidt (44: 14) found 14-15 pectoral rays in a number of examples from the eastern Atlantic.

Swim bladder elongated.

Slender, paired ovaries packed with eggs, filling almost the entire body cavity of one specimen.

Color. Adults probably silvery in life. Stomach and peritoneum coated with dark pigment.

Size. The largest recorded specimen is 245 mm (52: 4).

Development. At 7.5 mm the slender body is surrounded by the finfold, the caudal rays and the basal portion of the dorsal fin are beginning to appear,²² and a pair of large, conical teeth is present in the anterior part of the mandible. The most characteristic aspects of the pigmentation at sizes up to and possibly beyond 20 mm are several large chromatophores on the side near the midpoint of the body, a group of smaller pigment cells over the developing hypurals, and a short line of pigment behind the vent (later in development this line is behind the anal fin).

By the time the growing fish reaches 13 mm, rays have appeared in most of the fins, though a nearly continuous finfold is still present. The pectorals are very large and reach almost to the level of the dorsal origin. Considerable pigmentation has developed on the sides in the area below the dorsal fin.

At 20 mm the finfold has disappeared, leaving a well-defined dorsal adipose fin. The caudal fin is slightly forked, and the pectoral fin is relatively smaller, no longer reaching to the level of the dorsal origin. The sides are almost completely pigmented with the exception of a characteristic clear area at the end of the caudal peduncle. The chromatophores are ranged along the sides in parallel rows following the myomeres.²³

Habits. In the northeastern Atlantic, *N. groenlandica* apparently spawns mostly in the spring and early summer, but probably earlier in the southern part of its range. The smallest postlarvae were taken in water of 8 to 10°C (44).

In spite of its silvery color, *N. groenlandica* seems not to be a surface fish, for it has been taken most frequently with 300 to 1000 m.w. However, it was not found at extreme depths. It is evidently a social species, as 91 examples were taken in one haul and 93 in another.

Relationships. At the southern end of its range, *N. groenlandica* has been taken with *N. oblita*. The two species are easily separable by the relative position of the ventral fins; in *groenlandica* the ventrals are inserted ahead of a vertical from the posterior end of the dorsal fin; in *oblita* behind it. In addition, *groenlandica* is a more slender species than *oblita*. A population of *Nansenia* which is evidently very close to *N. groenlandica* is present in the Indian Ocean.²⁴

Range. Found mainly in the eastern North Atlantic, chiefly to the west and northwest of Great Britain. The most southerly recorded locality for *N. groenlandica* is

22. Schmidt (44: 15) and E. H. Ahlstrom (personal communication) have both noted that in *Nansenia*, *Argentina*, and other argentinoid fishes the rays begin to form out in the finfold rather than close to the body.

23. Schmidt (44) has presented figures and a more thorough description of development in *N. groenlandica*. His work should be consulted for additional details. He also discusses spawning, depth, distribution, and habits.

24. Cohen (13: 56) has discussed the problem of the Indian Ocean *Nansenia*. Unfortunately, more material is needed to properly settle the question.

48°43' N, west of Brittany. It is almost always taken in waters beyond the 1000-m curve. This species is known from only three examples in our area; one, the type, was taken at Fiskeness on the west coast of Greenland; the other two were taken from the stomachs of fish caught in the open ocean, one from a *Chiasmodon* collected at the surface, the other from *Makaira ampla*.

Synonyms and References:

- Microstomus grønlandicus* Reinhardt, Overs. Danske Vidensk. Selsk. Forh. i aar. 1839: 8 (orig. descr.; Fiskenesset, w. coast of Greenland, type in Univ. of Copenhagen Mus.); Reinhardt, Danske Vidensk. Selsk. Naturv. Math. Afh., 8, 1841: LXXIV (reprint. of orig. descr.).
- Microstoma grønlandicum* Gill, Proc. Acad. nat. Sci. Philad. (1861), Append., 1862: 54 (listed); Günther, Cat. Fishes Brit. Mus., 6, 1866: 205 (descr., Sea of Greenland); Jordan and Gilbert, Bull. U.S. nat. Mus., 16, 1883: 290 (listed); Jordan, Rep. U.S. Comm. Fish. (1885), 13, 1887: 830 (listed); Goode and Bean, Smithsonian. Contr. Knowl., 30, 1895: 53 (brief descr., refs.).
- Microstoma grønlandica* Gill, Smithsonian. misc. Coll., 283, 1873: 32 (listed); Ehrenbaum in Römer and Schaudinn, Fauna Arctica, 2 (1), 1901: 133 (refs.).
- Nansenia grønlandica* Jordan and Evermann, Bull. U.S. nat. Mus., 47 (1), 1896: 528 (descr., refs.); Schmidt, Rep. Danish oceanogr. Exped. Medit. 1908-1910, 2 Biol. A 5, 1918: 12, figs. 9-12, chart 2 (139 specimens from 27 locals., e. N. Atlant., descr., cf. *N. oblita*, synonym., transl. of orig. descr., devel., distr., taken over depths of 540-2775 m with 65-2800 m. w.); Jordan, Evermann, and Clark, Rep. U.S. Comm. Fish. (1928), 2, 1930: 68 (listed); Vladykov, Proc. N.S. Inst. Sci., 19, 1934-1935: 4, 6 (245 mm, from stomach of *Chiasmodon niger* taken at surface, 39°10' N, 69°40' W); Vladykov and McKenzie, Proc. N.S. Inst. Sci., 19, 1935: 52 (listed); Chapman, Proc. Calif. Acad. Sci., (4) 26, 1948: 18 (cf. *N. oblita*); Jensen, Spol. Zool. Mus. Hauniensis, 9, 1948: 92 (redescr. of holotype, refs., distr.); Saemundsson, Zool. Iceland, 4 (72), 1949: 95 (listed); Cohen, Stanford Ichthyol. Bull., 7 (3), 1958: 55 (counts on Vladykov specimen).
- Microstoma* sp. Holt and Byrne, 2nd Rep. Fish. Irish Atl. Slope, Fish. Ireland (1906), Sci. Invest., 5, 1908: 53 (55°1' N, 10°45' W, midwater trawl at 1150 fms. over 1200 fms., several postlarvae); 6th Rep. Fish. Irish Atl. Slope, Fish. Ireland (1912), Sci. Invest., 1, 1913: 26, fig. 11 (fig. of specimen 14.5 mm without caudal).

Doubtful References:

- Nansenia grønlandica* Norman, Sci. Rep. 'John Murray' Exped. 1933-1934, 7 (1), 1939: 17, fig. 4 (off Zanzibar and Maldives, 494-658 m, probably *N. macrolepis* or a Jap. species).
- Nansenia grønlandicus* Misra, Rec. Indian Mus. (1947), 45, 1949: 412 (synon., distr., follows Norman); 50, 1953: 395 (descr., distr., after Norman).

Negative References:

- Nansenia grønlandica* Tanaka, Fish. Japan, 1, 1911: 15, pl. 3, fig. 13 (Sagami Sea, equals *N. tanakai* Schmidt); Jordan, Tanaka, and Snyder, J. Coll. Sci., Tokyo, 33 (1), 1913: 46 (after Tanaka, equals *N. tanakai*); Kamohara, Offshore Bottom-Fish. Prov. Tosa, Shikoku, Japan, 1938: 8, fig. 1 [descr., equals *N. schmitti* (Fowler), or *N. tanakai* Schmidt, or *N. ardesiaca* Jordan and Thompson, or *N. macrolepis* (Gilchrist)]; Kamohara, Rep. Kôchi Univ. nat. Sci., Japan, 3, 1952: 13, fig. 9 (after Kamohara, 1938).

Genus *Microstoma* Cuvier 1817

Microstoma Cuvier, Règne Anim., 2, 1817: 184; type species by absolute tautonymy, *Gasteropelecus microstoma* Risso 1810. Nice.

Characters. Body very long. Predorsal distance greater than 60% of SL. Ventral fins originating in front of a vertical from origin of dorsal fin. No dorsal adipose fin. Eyes nontubular and directed laterally.

Range. Long known from only the Mediterranean and the tropical eastern Atlantic, *Microstoma* has recently been taken from the Gulf of Mexico and the temperate north-eastern Pacific. Its capture at the surface in the Gulf of Mexico, coupled with the fact that it ranges as far east in the Mediterranean as the Dodecanese Islands and into the Aegean Sea, stresses the point that *Microstoma* does not habitually frequent great depths. Its silvery color also suggests a fish of the upper water layers. It has been caught most often with 200 to 300 m.w., but at times with as much as 1000 m.w. It has been taken most frequently in surface waters over depths of 1000 m.²⁵

Remarks. Only a single species is presently assigned to this genus.

Microstoma microstoma (Risso) 1810

Figure 9

Study Material. A total of 11 specimens: 5 from Messina, USNM and ANSP; 1 from the Gulf of Mexico, CNHM; 5 from the eastern North Pacific, SU.

Description. Proportional dimensions in per cent of standard length, based on one specimen from the Gulf of Mexico and three from Messina, ranging in size from 88.9 to 161.2 mm SL. The mean first, followed by the range in parentheses.

Body: depth at dorsal fin 7.5 (7.3–7.7); width behind head 7.5 (7.2–8.1).

Caudal peduncle: least depth 4.5 (4.3–5.0).

Head: length 19.4 (18.9–20.2).

Snout: length in front of eye 4.0 (3.3–4.7).

Eyes: horizontal diameter 7.4 (7.1–7.8).

Fin base: dorsal 7.9 (7.4–8.3); anal 3.8 (3.4–4.3).

Fin length: pectoral 12.8 (12.4–13.1); ventral 8.3 (8.1–8.5).

Distance from tip of snout to: origin of anal fin 78.0 (75.2–80.5); origin of dorsal fin 64.2 (62.2–65.9); base of ventral fin 62.1 (58.4–64.7); base of pectoral fin 20.4 (20.6–21.0).

Lateral-line scales: about 50 (including those on caudal fin).

Branchiostegal rays: 2 (?).

Gill rakers: on first arch 6 + 1 + 14 (one from Messina).

Pyloric caeca: 7 (one from Messina).

An elongated, subcylindrical fish with the greatest depth of body about midway between origins of pectoral and ventral fins; dorsal profile extending in a straight line to dorsal fin origin, thence tapering to caudal peduncle; ventral profile extending in a straight line to the ventral fin origin, thence tapering to the caudal peduncle. Lateral line originating above opercle and running straight back in the midline of body, extending beyond caudal peduncle and onto caudal fin. Lateral-line scales wider and more adherent than other body scales.

25. Schmidt (44: 22) has given data on the occurrence, habits, and development of *Microstoma*.

Head with dorsal profile descending gradually to eye, there being interrupted by the dorsal rim of orbit, descending more steeply from eye to a point in front of nostrils, thence descending almost vertically to form the dorsal portion of the truncated snout; ventral profile ascending gently to a point below lower jaw, then rising vertically. Snout variable in relative length. Interorbital, in specimens with undamaged epidermis on top of head, broadly rounded and convex, sloping laterally into troughs; specimens with a damaged interorbital area generally with the unossified membranous dorsal surfaces of the interorbital canals lost, thus creating the impression that there are four prominent interorbital ridges. Several examples with remnants of a weakly developed adipose eyelid at anterior edge of orbit. Pupil horizontally elliptical. An orbital crescent of white tissue apparently lacking. Nostrils situated at upper corners of

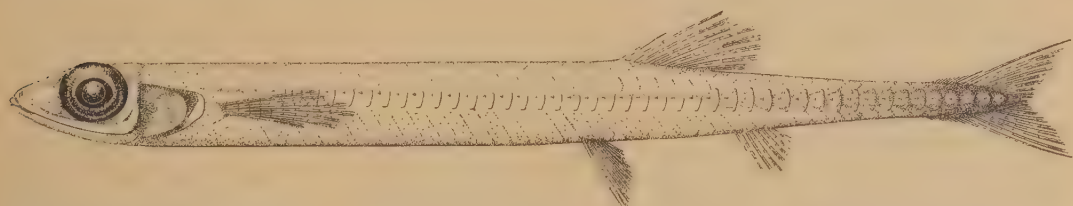


FIGURE 9. *Microstoma microstoma*, 162 mm SL, Gulf of Mexico, 22°N, 96°38'W, CNHM 59994. Drawn by Miriam Wilson.

the blunt snout, the anterior nostril facing forward, the posterior one laterally. Opercle longer than deep, a very thin, flap-like extension forming its posterior area, reaching almost to pectoral fin base. Gill opening reaching beyond upper angle of opercle and extending forward to about middle of opercle length. Branchiostegal rays broad, leaf-like appendages. Gill rakers medium-sized, compressed, relatively widely spaced, their bases not closely pressed together.

Jaws subequal, rounded, with a weak vertical ridge at symphysis of lower jaw. Maxillary with most of its area concealed beneath lachrymal and jugal; its posterior tip closer to eye than to snout.

Teeth compressed, in a single closely spaced row on dentary; head of vomer and possibly the palatines also carrying a row of weak, needle-like teeth. Tongue without teeth.

Dorsal fin base originating slightly behind a vertical from posterior end of ventral fin base. Anal fin base originating behind a vertical from posterior end of dorsal fin base. Pectoral fin base at an angle of 45° with the horizontal, closer to lateral than to ventral profile of body. Ventral fins inserted on ventral surface of body, covered basally by a scale sheath.

Swim bladder faintly colored with remnants of what was apparently a complete coating of silvery pigment.

Color. Adults mostly silvery in life, with opercles, caudal peduncle, and ventral midline of body ahead of ventral fins darkened. A specimen 45 mm SL taken off southern California shows the following color pattern: sides and dorsum of body between posterior ends of opercles and origin of ventral fins colored by large chromatophores dis-

tributed in lines along the septa. A wider, irregular band of smaller chromatophores along midline of body. From origin of ventral to caudal peduncle, smaller chromatophores invading the areas between septa, causing entire posterior region to appear dusky. Entire venter of fish thickly sprinkled with small chromatophores, giving it a dark appearance. Top of skull posterior to the interorbital brown. A large brown patch behind eye on posteroventral corner of preopercle and anterior edge of opercle. Lateral edges of mandibles and top of lower jaw dusky. A dark line running forward between nasal rosettes and spreading out over the upper lip. The transparent opercles overlaid by a delicate translucent sheen. Pectoral, anal, and caudal fins immaculate. Dorsal and ventral fins with distal 33–50% of their longer rays darkly colored.

Size. The largest specimen recorded is 197 mm SL (33 [1948]: 37).

*Development.*²⁶ Ripe eggs are from 1.60 to 1.72 mm diameter, with a large oil globule ranging from 0.48 to 0.52 mm diameter. The eggs of *M. microstoma* are similar to those of *Argentina silus* in having a vesicular yolk as well as the prominent oil globule.

The smallest larvae known, about 6.0 mm long, still have some yolk present. Rays have started to form in the caudal fin only. Characteristic pigmentation consists of a double row of pigment along the side of the postorbital part of the head which continues posteriorly on the ventral sides of the myomeres. A line of small chromatophores runs back on the ventral surface of the gut as well. The intestine is a bulky twisted structure which occupies considerable space in the little fish. In a 7-mm specimen from the Aegean Sea, a projecting portion of the intestine, equal in length to about 0.25 of the length of the fish, is free from the body.

Between 7.24 and 9.5 mm, the basal elements of the dorsal and anal fins begin to develop in the finfold. As previously noted for *Argentina silus*, the fin elements first form out in the finfold rather than adjacent to the body. It is in this size range that the ventral fins first make their appearance.

By 14 mm the finfold is present only in the area behind the median fins, and chromatophores have spread to the entire body.

The 17-mm stage is similar to an adult in most major respects. My measurements on various sizes of adolescent and adult specimens, 20.0 to 161.2 mm SL, show that considerable allometric growth takes place. Greatest body depth, least depth of caudal peduncle, head length, postorbital length of head, preanal distance, preventral distance, and possibly predorsal distance, all tend to show a relative decrease as the absolute length of the fish increases. Thus larger fishes appear more slender, with shorter heads and with more advanced anal, dorsal, and ventral fins, than do smaller fishes.

Habits. Spawning in the Mediterranean evidently occurs at almost any time throughout the year, though it is apparently more common in the winter. Schmidt (44) believes that the species there tends to frequent waters which stay at about 13°C during the entire year.

²⁶ Schmidt (44: 25–27, fig. 14) and Sanzo (42: 32–36, pl. 3, figs. 1–8) have presented accounts and figures of development in this species. The account of *Development* is abstracted from their work.

Although *M. microstoma* has long been known, particularly in the Strait of Messina, and although a considerable literature has accumulated about it, it evidently does not occur in any great abundance. The largest single collection consisted of nine specimens (44), but the fish is most often encountered singly.

Synonyms and References:

Gasteropelecus microstoma Risso, Ichthyol. Nice, 1810: 356, in part (orig. descr.; Nice, near mouth of Var R., France, lectotype, MNHN 3668); Bertin, Bull. Mus. Hist. nat. Paris, (2) 12 (6), 1940: 308 (type in MNHN).

Microstoma microstoma Cuvier, Règne Anim., 2, 1817: 184 (descr., new genus proposed); Brauer, Wiss. Ergebn. 'VALDIVIA,' 15 (1), 1906: 10, fig. 1, in part? (descr., synon., 3°31'N, 7°25'E, Gulf of Guinea, 600 m); 15 (2), 1908: 169 (eye descr.); Fage, Ann. Inst. océanogr. Monaco, 1 (7), 1910: 3 (larvae, near Monaco, between 0 and 308 m); Fowler, Proc. Acad. nat. Sci. Philad. (1911), 63, 1911-1912: 556 (Italy); Fowler, Bull. Amer. Mus. nat. Hist., 70 (1), 1936: 197, fig. 85 (descr., synon., distr., discus.); Lozano Rey, Mem. Acad. Cien. Madrid, Ser. Cien. Nat., 11, 1947: 135, fig. 30 (descr., synon., distr.); Chapman, Proc. Calif. Acad. Sci., (4) 26, 1948: 17 (descr., distr.); Maul, Bol. Mus. Municipal Funchal, 3 (5), 1948: 36, fig. 15 (descr., synon., near surface, Madeira); Grey, Copeia, 1956: 242, fig. 1 (descr., cf. other specimens, 22°N, 96°38'W, surface, Gulf of Mexico); Cohen, Copeia, 1958: 133 (nomencl., 5 specimens from e. N. Pacific between central Baja California and Monterey Bay, Calif.).

Microstoma rotundata Risso, Hist. Nat. Europe Mérid., 3, 1826: 474, pl. 14, fig. 36, in part (NOMEN NOVUM PRO *Gasteropelecus microstoma* Risso 1810, descr., refs.); Bonaparte, Cat. Metod. Pesci Europ., 1846: 25 (listed, synon.); Moreau, Hist. Nat. Poiss. France, 3, 1881: 557 (descr., synon.); Reguis, Bull. Soc. Etud. sci. arch. Draguignan, 13, 1882: 176 (Nice); Cocco, Nat. Sicil., 4, 1885: 294 (listed).

Microstoma argenteum Valenciennes, Règne Anim., Poiss., 2, 1836: pl. 97 (brief descr., Mediterranean); Valenciennes, Hist. Nat. Poiss., 18, 1846: 266, pl. 544 (NOMEN NOVUM PRO *Gasteropelecus microstoma* Risso 1810, descr., discus. nomencl., Nice, France; Sardinia, Italy); Schmidt, Rep. Danish oceanogr. Exped. Medit. 1908-1910, 2 Biol. A 5, 1918: 22, figs. 15-17, chart 2 (descr., synon., 27 specimens from 12 locals. in Medit., from s. Spain to Dodecanese Is., cf. *N. oblita*, postlarval devel., habits, nomencl.); Sanzo, Monogr. Fauna Flora Golfo Napoli, 38 (1a), 1931: 32, pl. 3, figs. 1-8 (devel., habits); DeBuen, Notas Inst. Español Océanogr., (2) 88, 1935: 47 (synon.); Bertin, Bull. Mus. Hist. nat. Paris, (2) 12 (6), 1940: 308 (type in MNHN).

Microstoma mediterranea Cuvier, Anim. Kingd., 2, 1837: pl. 59, fig. 2 (new name in caption to fig.).

Microstoma rotundatum Günther, Cat. Fishes Brit. Mus., 6, 1866: 204, in part (descr., synon., Messina, Medit.); Canestrini in Cornalia et al., Fauna Ital., Pesci, 3, 1871-1872: 130 (descr., synon., distr.); Doderlein, Atti Accad. Sci. Palermo, N.S. 6, 1878-1879: 56 (Sicily); Giglioli, Elenco Mammiferi, Cat. Anfibi. Pesci Ital., 1880: 42 (Messina); Carus, Prod. Faunae Medit., 2, 1893: 556 (descr.); Goode and Bean, Smithsonian. Contr. Knowl., 30, 1895: 53, fig. 59 (descr., synon., Messina); Ariola, Ann. Mus. Civ. Stor. Nat. Genova, (3) 1, 1904: 157 (synon., Gulf of Genoa, nomencl.); Mazzarelli, Riv. mens. Pesca Idrobiol., 4, 1909, not seen (Messina); 5, 1910, not seen (larvae, Messina); Lav. Ist. Zool., Pavia, 3, 1911: 9 (larvae, adolesc. at Messina); Tortonese and Trotti, Atti Accad. Ligure Sci. Lett., Genova, 6 (1), 1949: 35 (distr.).

Microstoma argenteum rotundatum Facciola, Nat. Sicil. (1886-1887), 6 (10), 1887: 193 (cf. *M. a. oblita*).

Doubtful References:

Microstoma rotundatum Gill, Proc. Acad. nat. Sci. Philad. (1864), 1864: 188 (probably *Nansenia oblita*); Lo Bianco, Mitt. Zool. Sta. Neapel, 16, 1903: 158, pl. 8, fig. 18 (two postlarvae from Capri, Italy; one, possibly both, *Nansenia oblita*); 19, 1909: 726 (after Lo Bianco, 1903).

Genus *Xenophthalmichthys* Regan 1925

Xenophthalmichthys Regan, Ann. Mag. nat. Hist., (9) 15, 1925: 59; type species by monotypy, *Xenophthalmichthys danae* Regan 1925. Carribean Sea, near St. Lucia, 14°N, 61°40'W, 2500 m.w.

Prososcopa Rass, Zool. Zhurn., 40, 1961: 1858; type species by original designation, *Prososcopa stilbia* Rass 1961. Java Trench area, 10°18'S, 110°23'E.

Characters. Body very elongated, predorsal distance less than 60% of SL (in adults). Ventral fin base well in front of a vertical from anterior end of dorsal fin base. No dorsal adipose fin. Eyes tubular and directed anteriorly (in adults).

Range. Known from the equatorial Atlantic and the Indian Ocean south of Java.

Species. Perhaps two.

Xenophthalmichthys danae Regan 1925

Study Material. None.²⁷

Figure 10

Description. Proportional dimensions in per cent of standard length, given for three specimens, the type first, 83 mm SL, followed by a specimen of 59 mm SL and another of 16.5 mm SL.

Body: depth between head and ventrals 7.0, 6.0, 11.5.

Caudal peduncle: least depth 2.9, 2.7, 4.5.

Head: length 14.6, 15.5, 17.5.

Snout: length in front of eye 1.2, 1.7, 2.3.

Eyes: longitudinal diameter 6.0, 7.0, 7.5; lens 3.0, 2.9, 2.1; distance between 1.1, 1.5, 2.8.

Distance from tip of snout to: origin

of dorsal fin 52, 54, 62; origin of anal fin 30, 28, 27; base of ventral fin 40, 44, 50.

Distance from: ventral to anal 30, 28, 27; anal to caudal 30, 28, 23.

Longitudinal scale rows: about 50.

Branchiostegal rays: 3.

Fin rays: dorsal 11, 10, 10; anal 10, 10, 9; pectoral 7, 7, 7; ventral 9, 9, 8-9.

Pyloric caeca: 6.

A slender fish, subcylindrical anteriorly, more compressed posteriorly, the greatest depth of body between the dorsal and pectoral fins. Lateral line seemingly originating above pectoral fin base and running straight back on midline of the body, beyond caudal peduncle and onto caudal fin; lateral-line scales resembling those of *Microstoma* and at least some *Nansenia* species in being wider and more adherent than the body scales.

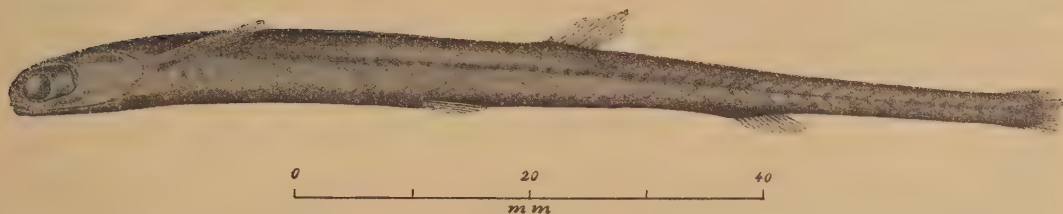
The dorsal profile of the head descending gently to the area in front of eye, thence more steeply to form the upper portion of the very short truncated snout; ventral profile appearing almost flat. Eyes large, anteriorly directed, tubular, projecting out over margins of head, thus providing the fish with dorsal, ventral, and lateral as well as anterior fields of vision; binocular vision must be possible anteriorly. Opercle seems to resemble that of *Microstoma* in being a thin, elongated bone, with the gill opening extending far forward dorsally.

Teeth on dentary, vomer, and palatine.

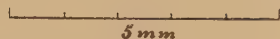
Dorsal fin base beginning well behind a vertical from posterior end of ventral

27. The present account is taken from Bertelsen (6).

1



3



2

4

FIGURE 10. *Xenophthalmichthys danae*. 1. 88 mm SL, holotype, near St. Lucia, 14°N , $61^{\circ}40'\text{W}$, DANA collections. 2. Dorsal view of specimen 59 mm SL, near Freetown, $8^{\circ}26'\text{N}$, $15^{\circ}11'\text{W}$, DANA collections. 3. Frontal view of same. 4. Ventral view of same. From Bertelsen (6).

fin base. Anal fin base beginning behind a vertical from posterior end of dorsal fin base. Pectoral fin base originating about 67% of the way up the side, immediately below lateral line, and at an angle of about 60° from the horizontal. Ventral fins inserted on ventral surface of body.

Swim bladder not observed, but a detailed search was not made.

Color. Bertelsen has reported that a preserved specimen "is dark brownish with a brassy sheen on the sides and belly. The gill covers are silvery." The postlarval pigmentation is similar to that in postlarval *Microstoma*.

Development. A specimen 14.5 mm SL differs from the two known adult specimens chiefly in having the eyes nontubular and directed anterolaterally rather than anteriorly; also, it differs proportionally from the two adults in being deeper-bodied, in having a longer snout, a broader interorbital, greater prefrontal, predorsal, and preanal distances, a shorter anal-to-caudal distance, and a deeper caudal peduncle.

References:

Xenopthalmichthys danae Regan, Ann. Mag. nat. Hist., (9) 15, 1925: 59 (orig. descr., Caribbean Sea, near St. Lucia, 14°N, 61°40'W, 2500 m. w.); Bertelsen, 'Dana' Rep., 45, 1958: 1, text figs. 1-6, pl. 1, figs. 1-4 (redescr. of type, descr. of another adult and one postlarva, syst. position; postlarva cf. *Microstoma* postlarva; figs. of adults, postlarva, and lat.-line scales).

Family BATHYLAGIDAE

Characters. Generally compressed laterally; some rather deep-bodied with deep caudal peduncle; others with a robust body tapering to a narrow caudal peduncle; still others slender. Anal fin originating on posterior third of body, and many species with an elongated base. Pectoral fins originating slightly behind head and close to ventral surface of body. Dorsal adipose fin present or absent. Scales deciduous. Eyes large and directed laterally in some species, anterolaterally in others, but not tubular. Supra-orbital bones present. Interorbital space not very narrow, more than half as wide as depth of caudal peduncle. Photophores absent, but luminous tissue reported on scales and fins of one species (3: 116). Frontals not fused; parietals not meeting in the midline; premaxillaries present; postcleithra and mesocoracoids absent. Swim bladder absent. Teeth²⁸ present on head of vomer and dentaries; present or absent on palatines. Pseudobranch located lateral to anterior half of upper arm of first gill arch. Gill membranes broadly united and separate from isthmus. Branchiostegals 2 (in recent species). Opisthotic reduced; orbitosphenoid present.²⁸

Color. Two general types of coloration. One, seemingly characteristic of species of the deeper water layers, consists of black fragments of skin around the scale pockets; these species may be relatively dark in life. The second type, found in fishes which usually inhabit the upper water layers, is predominately light, usually with considerable amounts of silvery pigment on the body and head.

Remarks. In a number of *Bathylagus* species, larvae have their eyes set off from the head on short stalks.²⁹ In addition, body proportions may undergo considerable change during growth.

Range. Distribution is probably world-wide. Bathylagids range from Davis Strait to Antarctica in the Atlantic and are known from Bering Sea, the Okhotsk Sea, and from both sides of the North Pacific. The apparent absence of this group

28. Skeletal characters based on alizarin specimens of *B. pacificus* and *B. stilbius*.

29. Beebe (3: 118) has reported stalked eyes in the larvae of a Bermuda species of *Bathylagus*, and Tåning (49: 269) has found them in the larvae of a fish questioningly identified as *Bathylagus benedicti*. Tåning has also noted that certain other stylophthalmodontid types of larvae are probably species of *Bathylagus*.

in the South Pacific may be due to the dearth of bathypelagic collections from this great area.

Little definite information on the depth distribution of bathylagids has ever been published, inasmuch as few if any collections have ever been taken with closing nets; however, specimens have been taken in nets fished between the surface and about 2000 fathoms. At least one North Pacific bathylagid carries on daily vertical migrations and is apparently associated with the deep scattering layer of organisms (51: 224).

Genera. Three genera and one subgenus have been proposed for recent bathylagid fishes. With our present knowledge of the family they are not separable, and pending a revision of the family, the recent species are all placed in the same genus.

Genus *Bathylagus* Günther 1878

Bathylagus Günther, Ann. Mag. nat. Hist., (5) 2, 1878: 248; type species, *Bathylagus antarcticus* Günther 1878 or *Bathylagus atlanticus* Günther 1878.³⁰

Generic Synonyms:

Leuroglossus Gilbert, Proc. U.S. nat. Mus., 13, 1890: 57; type species by original designation, *Leuroglossus stilbins* Gilbert 1890; ALBATROSS St. 2997, 24°39'N, 110°34'W, St. 2998, 24°51'N, 110°39'W; both in Gulf of California.

? *Therobromus* Lucas in Jordan and Gilbert, Fur Seals and . . . Islands, N. Pacif. (1896-1897), 3 (18), 1899: 440; type species by monotypy, *Therobromus callorhini* Lucas 1899 (bones from fur seal stomachs); several localities in Bering Sea.

Bathylagoides (subg.) Whitley, J. Proc. roy. Soc. N.S.W. (1949-1950), 1951: 61; type species by original designation, *Bathylagus argyrogaster* Norman 1930; 2°43'S, 00°56'W.

Characters. As for the family.

Remarks. Of the 27 recent species described in the genus *Bathylagus* or its synonyms, five occur within our area. A lack of material precludes the possibility of giving a key to any but western North Atlantic forms, and even this should be considered tentative.

Key to Western North Atlantic Species of *Bathylagus*

- 1 a. Gill opening extending at least halfway up the side of body.
 - 2 a. Anal fin base equal to or shorter than length of caudal peduncle; anal rays 13.
greyae Cohen 1958, p. 36.
 - 2 b. Anal fin base longer than length of caudal peduncle; anal rays 19-21.
 - 3 a. Dark pigment present on some scale pockets.
compsus Cohen 1958, p. 37.
 - 3 b. Dark pigment lacking on all scale pockets.
longirostris Maul 1948, p. 40.
- 1 b. Gill opening not extending halfway up the side of body.

30. Follett and Cohen (20: 73-78) have discussed the complexities of this problem in a request for a ruling from the International Commission on Zoological Nomenclature.

4a. About 40 lateral-line scales; eye diameter 8.8–13.0 % of SL.

euryops Goode and Bean 1895, p. 42.

4b. About 50 lateral-line scales; eye diameter 5.9–8.0 % of SL.

bericoides (Borodin) 1929, p. 46.

Bathylagus greyae Cohen 1958

Figure 11

Study Material. Two specimens: the holotype, 71 mm SL, CNHM; and a single paratype, 35.5 mm SL, SU.

Distinctive Characters. *B. greyae* is easily distinguished from other western North Atlantic *Bathylagus* by a gill opening that reaches more than halfway up the side of the body, and an anal fin base equal to or shorter than the length of the caudal peduncle. Its closest known relative is *B. ochotensis* of Japanese seas, from which it differs in having the anal fin base shorter than the dorsal fin base.

Description. Proportional dimensions in per cent of standard length, given for two specimens, the holotype first, 71 mm SL, followed by the paratype, 35.5 mm SL.

Body: depth at dorsal fin 13.4, 16.9.

of anal fin 81.0, 79.1; origin of dorsal

Caudal peduncle: least depth 8.4,

fin 48.2, 50.7; base of ventral fin 58.4,

8.4.

61.1; base of pectoral fin 28.9, 32.7.

Head: length 25.3, 29.6.

Snout: length in front of eye 5.9,

Lateral-line scale pockets: 45–50(?).

7.0.

Branchiostegal rays: 2.

Eyes: horizontal diameter 9.4, —.

Gill rakers: on lower arm of first

Fin base: dorsal 12.0, 11.8; anal

arch 16.

9.7, 9.9.

Distance from tip of snout to: origin

Fin rays: dorsal 11, 13; anal 13,

13; pectoral 12, 13; ventral 10, 11.

A slender compressed fish with the greatest depth behind head, tapering very little to the caudal peduncle.

Head with dorsal profile sloping gently downward in an almost straight line from a point behind eye to a point near nostrils, whence it descends more steeply; dorsal rim of orbit projecting into the dorsal profile. Eyes directed laterally, lacking adipose eyelids. A crescent of white material over portions of iris. Interorbital area between supraorbital canals broadly rounded. The height of the gill opening more than half the greatest height of body and extending beyond dorsal edge of pectoral fin base by a distance equal to about 2.5 times the pectoral fin base in the holotype and about 1.5 times in the paratype.

Jaws rounded and equal. Posterior edge of maxillary not reaching a vertical from anterior edge of orbit. Minute papillae on epidermis covering maxillary, premaxillary, and dentary.

The mouth of the holotype is damaged, making it difficult to discern any details of dentition; however, the single row of conical upper teeth is apparently restricted to the head of vomer. Compressed dentary teeth smaller than vomerine teeth excepting a pair of small, spike-like teeth projecting at the symphysis of dentaries.

Both dorsal and anal fin bases protruding from body. Dorsal fin originating close to midpoint of body, its base slightly longer than that of anal fin base. Dorsal adipose fin over center of anal fin base. Anal fin base equal in length to that of caudal peduncle. Pectoral fin inserted a short distance behind head on ventrolateral contours of body. Ventral fins inserted on ventral surface of body under posterior part of dorsal fin base. Ventral adipose fin weak, directly anterior to vent on paratype.

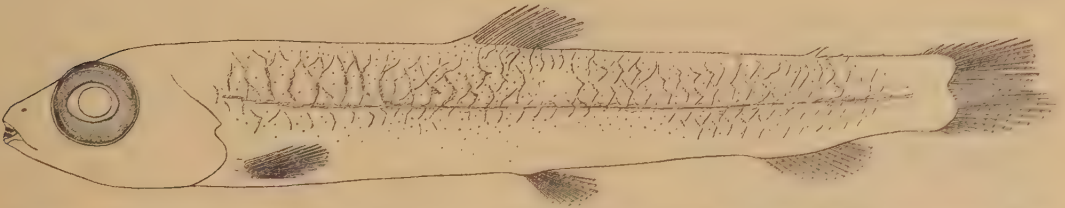


FIGURE 11. *Bathylagus greyae*, 71 mm SL, holotype, Bermuda, 32°13.5' N, 64°32.5' W, CNHM 49730. From Cohen (15).

Color. Ventral half of the holotype with a pale, straw-colored ground color; the dorsal half brown. Opercle and snout dusky. Small, dark-brown chromatophores scattered at random over sides on a field of still smaller, more densely distributed, light-brown chromatophores. Sides of head and all fins lightly peppered with dark brown pigment cells. Dark pigment also thickly distributed on margins of scale pockets. Some of scale pockets bearing remnants of a purplish, translucent material which is common to a number of *Bathylagus* species. Paratype faded badly, little pigmentation remaining.

Reference:

Bathylagus greyae Cohen, *Breviora*, Mus. comp. Zool., 98, 1958: 5, fig. 2 (orig. descr.; holotype CNHM 49730, 32°13.5' N, 64°32.5' W, Bermuda, 500–550 m; paratype SU 50974, Bermuda, 1646–0 m).

Bathylagus compsus Cohen 1958

Figure 12

Study Material. Nine specimens: the holotype and a single paratype, 44.4 and 38 mm SL, respectively, USNM; 2 alizarin specimens from Bermuda, SU; 2 from the Bahamas and 3 from Bermuda, BOC.

Distinctive Characters. *B. compsus* is set off from other *Bathylagus* by the com-

bination of an extensive gill opening that reaches halfway up the side of the body; an anal fin base longer than the length of the caudal peduncle; and dark pigment on the margins of the scale pockets.

Description. Proportional dimensions in per cent of standard length, given for two specimens, the holotype first, 44.4 mm SL, followed by the paratype, 38 mm SL.

<i>Body:</i> depth at dorsal fin 16.9, 15.3.	fin 47.3, 50.0; base of ventral fin 52.5,
<i>Caudal peduncle:</i> least depth 6.3,	52.1; base of pectoral fin 27.0, —.
6.6.	
<i>Head:</i> length 25.0, 26.3.	<i>Lateral-line scale pockets:</i> about
<i>Snout:</i> length in front of eye 5.6,	40 (3).
5.3.	<i>Branchiostegal rays:</i> 2.
<i>Eyes:</i> horizontal diameter 10.0, 9.2;	<i>Gill rakers:</i> on lower arm of first
distance between 9.0, —.	arch 14–16.
<i>Fin base:</i> dorsal 8.8, 6.8; anal 16.9	<i>Fin rays:</i> dorsal 11, 10; anal 19,
15.0.	20; pectoral 9, 9; ventral 9, 10.
<i>Distance from tip of snout to:</i> origin	<i>Vertebrae:</i> 51 (3).
of anal fin 75.9, 76.8; origin of dorsal	<i>Pyloric caeca:</i> 6 (3).

A graceful, slender fish with the greatest depth a short distance behind the head, tapering to the caudal peduncle.

Dorsal profile of head descending from nape to interorbital in almost a straight line, then curving downward near the anterior edge of orbit and descending to a point above the nares, where another inflection occurs, causing the profile to drop more steeply to the upper lip; dorsal rim of orbit entering the dorsal profile in the smaller specimen but not in the larger; ventral profile rising gently, less steeply than the dorsal profile descends. Interorbital area broadly concave between supraorbital canals. Eyes directed laterally. Adipose eyelids absent. A crescent of white tissue over the iris of posterior half of eye. Gill opening slightly less in height than half the greatest height of body, extending beyond dorsal edge of pectoral fin base by a distance equal to 2.5 times the length of pectoral fin base.

Jaws rounded and subequal at the tips. Maxillary extending back to a vertical from a point slightly in front of anterior edge of orbit. Minute papillae on ventral margins of maxillary and premaxillary.

Dorsal fin originating close to midpoint of body, its base raised above body. Dorsal adipose fin over posterior end of anal fin base. Anal fin base set off from body, longer than dorsal fin base and longer than length of caudal peduncle. Pectoral fin inserted a short distance behind head on ventrolateral contours of body. Ventral fins inserted on ventral surface of body under posterior part of dorsal fin base. All fins broken off short.

Luminous material has been reported on the fins and abdomens of adult specimens (3: 114–147).

Color. Adolescent specimens in alcohol with a light, yellow-brown ground color. Muzzle, opercular apparatus, and a ring around the orbit dark brown. Opercle overlaid with an iridescent sheen, probably silvery in life. Iris iridescent gun-metal blue, possibly silvery in life also. Dark lining of peritoneal cavity showing through body wall and outlining body cavity. A single row of large, dark chromatophores running entire length of body slightly below lateral line. A second and less distinct line parallel to first a short distance above lateral line. Venter lightly peppered with small, dark chromatophores, more densely distributed on dorsum. Brown pigment cells also on dorsal surface of head behind and before interorbital area and on cheeks. Caudal, dorsal, and adipose fins with scattered brown chromatophores. Anal, ventral, and pectoral fins immaculate



FIGURE 12. *Bathylagus compsus*, 44.4 mm SL, holotype, 39°45' N, 71°08' W, USNM 171755. From Cohen (15).

or bearing only very few pigment cells. Posterior half of body with ragged remnants of scale pockets colored by large, dark chromatophores. Adult specimens (3) with a light ground color and a silver sheen ventrally. Superimposed on the basic coloration, dark brown chromatophores and black-edged scale pockets. Lips, orbits, and outer wall of coelom black. The dark iris and opercles coated with a silvery pigment.

Size. The largest specimen recorded is 94 mm SL (3).

Development (3). Specimens 23 to 30 mm are striking in having small, stalked eyes (3: fig. 34). Paired fins are poorly developed, and the dorsal adipose fin is elongated. The color pattern consists of two series of black blotches, one above and the other below the lateral line, and two rows of black pigment spots, one on each side of the ventral midline, extending from the base of the pectoral fin to the origin of the anal fin.

In a number of specimens 25 to 50 mm long the eyes are normal in appearance, the paired fins are well developed, and the typical adolescent color pattern (described above) is present.

Specimens larger than 54 mm have the dorsal adipose fin reduced and the snout more blunt than do smaller specimens. Large examples are also deeper-bodied than adolescents or postlarvae.

Habits (3). Although the types of *B. compsus* are from 38 fathoms, 99 specimens from Bermuda were taken between 500 and 1000 fathoms. Bermuda populations of this species seem to live about 100 fathoms nearer the surface in the spring than in the fall. During the months of May to September inclusive, when hauls were made at

Bermuda, neither breeding condition of adults nor degree of development in the young showed any correlation with depth or season.

B. compsus is not a commonly encountered species, nor is more than a single fish often captured at one time, although as many as three have been taken on several occasions.

Range. Known from the type locality, near the edge of the continental shelf east of New Jersey and south of Cape Cod, from Bermuda, and from the Bahamas.

Synonyms and References:

Bathylagus glacialis Beebe, Zoologica, N.Y., 16, 1933: 114, figs. 33-46, non Regan 1913 (descr., devel., osteol., ecol., 99 specimens from Bermuda, 500-1000 fms.); Beebe, Zoologica, N.Y., 22 (3), 1937: 199 (listed).

Bathylagus euryops Parr, Bull. Bingham oceanogr. Coll., 3 (7), 1937: 41, non Goode and Bean (2 specimens, 23°55'N, 77°09'W, 4000-7000 feet w.; 2 specimens, 32°24'N, 64°29'W, 5000 feet w.; 1 specimen, 32°19'N, 64°33'W, 3000 feet w.).

Bathylagus compsus Cohen, Breviora, Mus. comp. Zool., 98, 1958: 1, fig. 1 (orig. descr., 39°45'N, 71°08'W, 38 fms.).

Bathylagus longirostris Maul 1948

Figure 13

Study Material. Three specimens: 1 from the Gulf of Mexico, CNHM; 2 from the central Pacific, POFI.

Distinctive Characters. *B. longirostris* is set off from other *Bathylagus* by the combination of an extensive gill opening that reaches more than halfway up the side of the body; an anal fin base longer than the length of the caudal peduncle; and the complete absence of dark pigment on the margins of the scale pockets.

Description. Proportional dimensions in per cent of standard length, based on the holotype from Madeira,³¹ a single specimen from the Gulf of Mexico, and two specimens from the central Pacific, the specimens ranging from 131.5 to 145.6 mm SL. The mean first, followed by the range in parentheses.

Body: depth at dorsal fin 14.6 (14.1-15.2).

Caudal peduncle: least depth 5.5 (5.2-5.8).

Head: length 19.5 (18.3-20.6).

Snout: length in front of eye 4.5 (4.1-5.1).

Eyes: horizontal diameter 7.1 (6.4-7.7); distance between 6.6 (5.1-7.7).

Fin base: dorsal 8.4 (8.1-8.8); anal 16.1 (15.6-17.1).

Distance from tip of snout to: origin

of anal fin 74.7 (72.8-77.2); origin of dorsal fin 45.5 (44.4-46.3); base of ventral fin 51.0 (50.0-53.8); base of pectoral fin 21.7 (19.8-23.5).

Lateral-line scale pockets: about 50.

Branchiostegal rays: 2.

Fin rays: dorsal 11 (11-12); anal 21 (19-21); pectoral 10 (9?-12); ventral 10 (9-10).

Vertebrae: 48 (one from Gulf of Mexico); 49, 51 (two from central Pacific).

31. Kindly examined for me by G. E. Maul, Curator of the Museu Municipal do Funchal.

Body compressed laterally, of medium depth, its greatest depth at or immediately in front of dorsal fin, whence it tapers very gradually to the relatively narrow caudal peduncle.

Dorsal profile of head descending in almost a straight line from nape to nostrils, then descending almost vertically, forming the dorsal portion of the truncated snout. Eyes laterally directed, not projecting into dorsal profile of head. A crescent of white tissue over the iris. Bony interorbital broadly concave between the supraorbital canals, a slight rise over the pineal body. Opercle fragile, scale-like, a number of finger-like extensions projecting beyond its posterior margin. Gill opening extending more than



FIGURE 13. *Bathylagus longirostris*, 134 mm SL, Central Pacific, 29°54'N, 168°32'W, POFI. Drawn by Esther Coogle.

halfway up the side of body, reaching beyond dorsal margin of pectoral fin base by a distance equal to more than twice the length of the base.

Maxillary obliquely placed, not extending past anterior margin of orbit. Minute papillae on both premaxillary and maxillary.

Teeth conical, about 35 on vomer and on palatines. A greater number of smaller compressed teeth on dentary.

Dorsal fin originating ahead of midpoint of body, its anterior end slightly raised above the general contour of the body. Dorsal adipose fin over posterior end of anal fin base. Anal fin base markedly set off from body, slightly less than twice the length of dorsal fin base and longer than length of caudal peduncle. Pectoral fin on a weak peduncle, inserted on the ventrolateral contours of body behind a vertical from posterior end of opercle. Ventral fins inserted on ventral surface of body under posterior part of dorsal fin base.

Color. Light-tan ground color interrupted ventrally by the dark peritoneum showing through the musculature and outlining the body cavity. Small brown chromatophores more densely distributed on dorsal than on ventral half of fish, giving this entire area a light-brown cast. Larger brown chromatophores irregularly distributed along midline of body in a wide, poorly defined band. Snout dusky. Opercle a metallic blue-black. Fins immaculate.

Habits. The Pacific specimens were taken in hauls between 100 m and the surface; the Gulf of Mexico fish was caught between 780 fathoms and the surface.

Relationships. A comparison of morphometric data from the type and Gulf of

Mexico specimen on the one hand and from the two Pacific specimens on the other shows that the Pacific specimens have slightly shorter preanal and predorsal distances, somewhat shorter heads, and smaller eyes. More material is needed from both areas before it can be said with any certainty that the populations are discrete.

Range. In the Atlantic the species is known from Madeira, and from the Gulf of Mexico south of Pensacola, Florida; in the Pacific from northwest of Hawaii.

References:

Bathylagus longirostris Maul, Bol. Mus. Municipal Funchal, 3 (5), 1948: 35, fig. 14 (orig. descr.; Madeira, type in MMF); Albuquerque, Portug. Acta Biol., (B) 5, 1954-1956: 239, fig. 132 (descr.); Cohen, Breviora, Mus. comp. Zool., 98, 1958: 8 (Gulf of Mexico S. of Pensacola, Florida; central Pacific, 30°16.5'N, 179°54'E; 29°54'N, 168°32'W).

Bathylagus euryops Goode and Bean 1895³²

Figure 14

Study Material. A total of 16 specimens from the western North Atlantic, the northernmost and easternmost location at 47°34'N, 43°11'W, the southernmost off Bermuda, and the westernmost at 39°29'N, 71°46'W, USNM (including the 4 syntypes of *B. euryops* and 2 of the syntypes of *B. benedicti*), MCZ, CNHM, BNM, WHOI.

Distinctive Characters. *B. euryops* may be distinguished from other western North Atlantic *Bathylagus* by a small gill opening; an anal fin base longer than the length of the caudal peduncle; the relatively large eye, 8.8 to 13.0% of SL; about 40 lateral-line scales; and the dark pigment on the scale pockets.

Description. Proportional dimensions in per cent of standard length, based on nine western North Atlantic specimens ranging from 57.5 to 156.9 mm SL. The mean first, followed by the range in parentheses.

Body: depth at dorsal fin 16.3 (13.9-19.4).

Caudal peduncle: depth 6.0 (4.8-7.5).

Head: length 23.5 (21.1-27.0).

Snout: length in front of eye 3.9 (3.2-5.4).

Eyes: horizontal diameter 10.4 (9.6-11.6).

Fin base: dorsal 8.2 (7.2-10.8); anal 16.2 (13.9-18.4).

Distance from tip of snout to: origin

of anal fin 76.1 (73.4-78.5); origin of dorsal fin 46.3 (44.2-48.5); base of ventral fin 50.9 (48.8-54.2); base of pectoral fin 26.2 (23.5-28.4).

Lateral-line scale pockets: about 40.

Gill rakers: on lower arm of first arch, 17, 18 (two specimens).

Fin rays: dorsal 10 (9-11); anal 17 (16-19); pectoral 9 (7-12); ventral 8 (7-9).

Vertebrae: 45 (44-46).

32. As treated here, a composite of at least two species. See *Relationships*, p. 44.

Body robust, compressed, with a relatively narrow caudal peduncle. Scale pockets on side of body large, about 4 or 5 rows between origins of dorsal and ventral fin bases. In specimens with scale pockets still intact, a small, darkly colored flap of skin projecting back from posterior margin of a number of pockets on the side, the flaps especially well developed along lateral line; some of the flaps bifid at the tip, others single. Several specimens encased in a thin, gelatinous layer.

Dorsal profile curving gently from dorsal fin base to eye, thence falling to the upper lip at an angle of $50-60^{\circ}$; ventral profile rising less steeply. Eyes relatively large, projecting strongly into the dorsal profile of head. A weakly developed orbital crescent around the posterior half of eye. Interorbital area translucent, the concavity



FIGURE 14. *Bathylagus euryops*, 113.6 mm SL, $36^{\circ}36'N$, $63^{\circ}37'W$, MCZ 34962. Drawn by Esther Coogler.

accentuated by the upward flare of the scale-like supraorbitals as they rise to accommodate the dorsal margins of eyes. The head, anteriorly, converging very markedly, thus giving the fish a definite anterior as well as lateral field of vision and almost certainly an area of binocular vision. Gill opening small, extending only one or two times the length of the pectoral fin base above that base; its dorsalmost extension terminating well below the plane of the center of the eye. With careful observation it is possible to see, in the more complete specimens, 3 or 4 small, flap-like projections originating on the anteroventral surface of the opercle; these flaps similar in form to the nearby posterior tips of the broad, scale-like branchiostegal rays. Gill rakers medium sized, compressed, their bases not closely appressed; inner margin of each raker on first arch carrying a row of short, fleshy tubercles. These structures are difficult to see in the types of both *B. euryops* and *B. benedicti* but are evident in more recently captured specimens.

Jaws subequal, both the upper and lower broadly rounded. Minute papillae (it is perhaps these structures which some ichthyologists have called premaxillary teeth) on skin over both jaws. Posterior tip of maxillary extending rearward slightly beyond a vertical from anterior margin of eye.

Teeth small and compressed in the lower jaws of a specimen 157 mm SL, in a single row of about 120 teeth; dentary teeth in smaller specimens decreasing in size towards symphysis. About 20 small, pointed conical teeth in an irregular row on head of vomer. Some specimens with 4 or 5 palatine teeth, apparently lacking in others.

Both the roof of mouth and the edentulous tongue bearing a number of small, fleshy, hemispherical bumps.

Dorsal fin inserted ahead of the midpoint of body. Dorsal adipose fin (in some specimens greatly reduced) present over posterior end of anal fin base. Anal fin base longer than length of caudal peduncle. Dorsal, anal, and ventral fins elevated from body. Pectoral fins on short but distinct peduncles. Ventral fins inserted below dorsal fin base.

Color. Margins of scale pockets dark, especially on ventral part of body; pockets of some specimens lined with a purplish deciduous tissue. One specimen almost entirely light purple.³³ Opercle bluish-black. Snout dusky. Skin of anterior ventral surface of head iridescent purplish. Body beneath scale pockets a light-brown ground color with small brown chromatophores scattered about. The stomach, the five pyloric caeca (in one specimen), and the lining of body cavity dark. Intestine lacking pigment.

Habits. The northern *Bathylagus* have been found to live between about 20 and 500 m as postlarvae, between 500 and 1500 m as adolescents and adults. Spawning in the area between the Faeroes and Greenland probably occurs during a limited period in the spring (49). Bermuda specimens were taken at depths ranging from 700 to 1800 m. Younger specimens were taken in the spring, older ones in the summer and fall. The stomach contents of several specimens consisted of small crustaceans (3).

Relationships. The type specimens of the nominal species *B. euryops* and *B. benedicti* were taken from the same general area east of New Jersey. Examination has shown that they are separable only by the fact that the types of *B. euryops* have shorter anal fin bases (13.9 and 14.9 % of SL) than does one of the types of *B. benedicti* (17.2 % of SL), the other syntype being mutilated. I have examined a specimen³⁴ which has an anal fin base intermediate in length (16.2 % of SL). For the present I consider *B. benedicti* a synonym of *B. euryops*.

I also place *B. elongatus* Roule in the synonymy of *B. euryops* as there is no way to distinguish Roule's figure and description from the material which I have examined.

Further complications arise in considering the early developmental stages of North Atlantic bathylagids. Tåning (49: 269-274, figs. 1-3) has questioningly identified as *B. benedicti* a series from "the area between the Faroes and Greenland as well as in the Atlantic part of the Denmark and Davis Straits." The postlarvae (18 to about 27 mm) of this species have stalk eyes and very characteristic pigmentation consisting most often of three, but sometimes four or five, large dendritic chromatophores along the sides.

Beebe (3: 100-114) took a species of *Bathylagus* at Bermuda which he identified as *B. benedicti*. The postlarvae (18 to 22 mm) have neither stalk eyes nor the characteristic chromatophores. Of added interest is the fact that specimens with both long (17.0 % of SL) and short (14.9 % of SL) anal fin bases were included in Beebe's material.

Holt and Byrne (25: 24-26, fig. 10) reported on a series from the Irish Atlantic

33. See also the figure of the holotype of *Bathylagus elongatus* Roule (38: 1, fig. 2) for color plate of purple *B. euryops*.

34. MCZ 34258, 156.9 mm SL, from between 30°29'N, 70°14'W and 39°46'N, 70°09'W.

slope ranging from 15 to 158 mm SL. These authors have figured a specimen 25 mm SL showing neither stalk eyes nor enlarged chromatophores. Neither do they mention these characters in their smaller specimens.

In the absence of critical material I can only point out that two species of North Atlantic *Bathylagus* with similar-appearing adults and dissimilar young are confused under the same name. The problem of which species should be called *euryps*, the northern one with the stalk-eyed young or the southern one with the normal-eyed young, remains to be solved.

Range. Specimens identified as *B. euryps*, *B. benedicti*, *B. elongatus*, and misidentified as *B. atlanticus* have been taken from localities in the western North Atlantic, from Bermuda northward to about 64°N in Davis Strait off the west coast of Greenland. Eastern North Atlantic catches are from near Cape Finisterre (type locality of *B. elongatus*), south and east of Ireland, between the Faeroes and Greenland, and in the southern part of Denmark Strait.

Records exist for *B. euryps* and *B. benedicti* from the South Atlantic and the Antarctic, and *B. euryps latifrons* has been reported from the Antarctic. Whether *B. euryps* has a true disjunct distribution or whether lack of comparative material has resulted in misidentification of the southern species remains to be seen.

Although it appears that the *Bathylagus* of Davis Strait is not the same species identified as *B. benedicti* at Bermuda, it is of interest that there is no temperature barrier between the two populations. The Bermuda specimens were taken between 700 and about 1800 m; temperature data for these depths at Bermuda (3: 6; 55: 14, fig. 8) show a range from about 14°C at the shallower depth to about 3.6°C at the greatest depth. The Davis Strait specimens were taken at depths ranging from 300 to 660 m;³⁵ water between 3°C and about 4.5°C might be found in these localities during the late spring and early summer (46), when the Davis Strait specimens were captured. Thus we see a considerably greater temperature difference within the Bermuda environment than between the Bermuda and Davis Strait environments.

Synonyms and References:

Bathylagus euryps Goode and Bean, *Smithson. Contr. Knowl.*, 30, 1895: 55, fig. 63 (orig. descr.; 39°29'N, 71°46'W, 693 fms., USNM 35420; 39°52'N, 70°30'W, about 600 fms., USNM 31861; 40°09'N, 67°09'W, 1356 fms., USNM 39477); Jordan and Evermann, *Bull. U.S. nat. Mus.*, 47 (1), 1896: 529 (descr., after Goode and Bean); Garman, *Mem. Mus. comp. Zool. Harvard*, 24, 1899: 403 (listed); Jordan, Evermann, and Clark, *Rep. U.S. Comm. Fish.* (1928), 2, 1930: 69 (listed).

Bathylagus benedicti Goode and Bean, *Smithson. Contr. Knowl.*, 30, 1895: 55, fig. 64 (orig. descr.; 39°44'N, 71°04'W, 1022 fms., USNM 33510; 38°59'N, 70°07'W, 1344 fms., USNM 44579); Jordan and Evermann, *Bull. U.S. nat. Mus.*, 47 (1), 1896: 529, fig. 234 (descr., after Goode and Bean); Garman, *Mem. Mus. comp. Zool. Harvard*, 24, 1899: 403 (listed); Jordan, Evermann, and Clark, *Rep. U.S. Comm. Fish.* (1928), 2, 1930: 69 (listed).

Questionable References:

Bathylagus euryps latifrons Lönnberg, *Wiss. Ergebn. schwed. Südpolar-exped.*, 5 (6), 1905: 67 (orig. descr.; 49°56'S, 49°56'W, 2700 m, type in NHR).

35. These depths are only approximate, as Jensen (27: 94) has given only the amount of wire out. I have estimated the depth of net as being one-third the wire out.

- Bathylagus atlanticus*, not of Günther 1887, Holt and Byrne, 1st Rep. Fish. Irish Atl. Slope, Fish. Ireland (1905), Sci. Invest., 2, 1906: 6, pl. 1, figs. 3 and 4 (descr., off County Mayo, Ireland, 1000–1500 fms., cf. type of *B. atlanticus*); 4th Rep. Fish. Irish Atl. Slope, Fish. Ireland (1908), Sci. Invest., 5, 1910: 3 (listed); Norman, 'Discovery' Rep., 2, 1930: 274, in part (off sw. Ireland, brief descr.); Borodin, Bull. Mus. comp. Zool. Harvard, 72 (3), 1931: 63 (descr., 33°50'N, 63°55'W, 1500 m).
- Bathylagus euryops* Holt and Byrne, 6th Rep. Fish. Irish Atl. Slope, Fish. Ireland (1912), Sci. Invest., 1, 1913: 24–26, fig. 10 (descr., 13 specimens, 15–158 mm, off Irish Atlantic slope, 400–900 fms., redeterm. of specimen previously called *B. atlanticus*); Publ. Circ. Cons. int. Explor. Mer, ed. 2, 12, 1914: 56 (distr.); Norman, 'Discovery' Rep., 2, 1930: 277 (brief descr., ca. 34°S, 16°E, 850–950 m; 60°48'S, 51°00'W, 1000–1100 m; 38°20'S, 22°18'W, 1800–2000 m; 51°35'N, 11°55'W, 720 fms.).
- Bathylagus elongatus* Roule, Bull. Inst. océanogr. Monaco, 320, 1916: 8 (orig. descr.; near Cape Finisterre, type in MOM); Roule, Résult. Camp. sci. Monaco, 52, 1919: 22, pl. 1, fig. 2 (redescr. type); De Buen, Notas Inst. Español Océanogr., (2) 88, 1935: 47 (listed); Lozano Rey, Mem. Acad. Cien. Madrid, Ser. Cien. Nat., 11, 1947: 139, fig. 32 (descr., after Roule); Belloc, Bull. Inst. océanogr. Monaco, 958, 1949: 4 (type in MOM).
- Bathylagus benedicti* Norman, 'Discovery' Rep., 2, 1930: 277 (brief descr., 41°43'S, 42°20'W, 2000–0 m; 53°25'S, 35°15'W, 1025–1275 m); Tåning, Vidensk. Medd. dansk naturh. Foren., Kbh., 92, 1931: 269, figs. 1–3 (postlarval stages with stalk eyes, between Faeroes and Greenland, Atlant. part of Denmark and Greenland straits); Beebe, Zoologica, N.Y., 16, 1933: 100, figs. 26–31 (descr., devel., ecol., Bermuda, 400–1000 fms.); Jensen, Spol. Zool. Mus. Hauniensis, 9, 1948: 93, chart 5 (descr., Davis Strait, refs.); Kotthaus and Krefft, Ber. Deutsch. Wiss. Komm. Meeresforsch., N.S. 14 (3), 1957: 171 (61°46'N, 50°38'W, from gut of *Gadus callarias*).
- Bathylagus glacialis* Norman, 'Discovery' Rep., 2, 1930, in part: 275 (brief descr., one of types of *B. glacialis* Regan from Antarctica is *B. euryops*); Grey, Fieldiana: Zool., 37, 1955: 284, not of Regan (Bermuda, 730–820 m).
- Negative Reference:
- Bathylagus euryops* Parr, Bull. Bingham oceanogr. Coll., 3 (7), 1937: 41 (23°55'N, 77°09'W; 32°24'N, 64°29'W; 32°19'N, 64°33'W; equals *Bathylagus compsus* Cohen).

Bathylagus bericoides (Borodin) 1929

Figure 15

Study Material. A total of 11 specimens: the type, from mid-Atlantic, MCZ 31627; 2 from near Bermuda, MCZ and SU; 1 from the Bahamas, BOC; 1 from the Gulf of Mexico, CNHM; 6 from the Central Pacific, POFI.

Distinctive Characters. *B. bericoides* may be distinguished from other *Bathylagus* by small gill openings, not extending halfway up the side of the body; an anal fin base longer than the length of the caudal peduncle; the small eye, 5.9–8.0 % of SL; about 50 lateral-line scales; and the very large, darkly colored scale pockets.

Description. Proportional dimensions in per cent of standard length, based on the Atlantic specimens cited above, ranging from 125.6 to 183 mm SL. The mean first, followed by the range in parentheses.

Body: depth at dorsal fin 15.9
(14.8–16.6).

Caudal peduncle: depth 6.2 (5.9–7.1).

Head: length 17.6 (17.0–18.1).

Snout: length in front of eye 3.1
(2.8–3.5).

Eyes: horizontal diameter 6.8 (6.6–7.2).

Fin base: dorsal 8.2 (8.0–8.4); anal 15.5 (13.5–17.2).

Distance from tip of snout to: origin of anal fin 77.6 (76.4–79.2); origin of dorsal fin 44.3 (42.8–45.7); base of ventral fin 51.1 (49.5–52.2); base of pectoral fin 19.3 (18.7–20.1).

Lateral-line scale pockets: about 50.

Branchiostegal rays: 2.

Fin rays: dorsal 10 (10–11); anal 18–22; pectoral 10 (10–12); ventral 10 (9–10).

Vertebrae: 48, 49 (two from Atlantic); 50, 51, 52 (three from Pacific).

Body elongated, compressed, with a relatively deep caudal peduncle. Scale pockets on side of body very large, only 3 or 4 rows between the origins of dorsal and ventral fin bases. The very large scales along the lateral line apparently alternating with

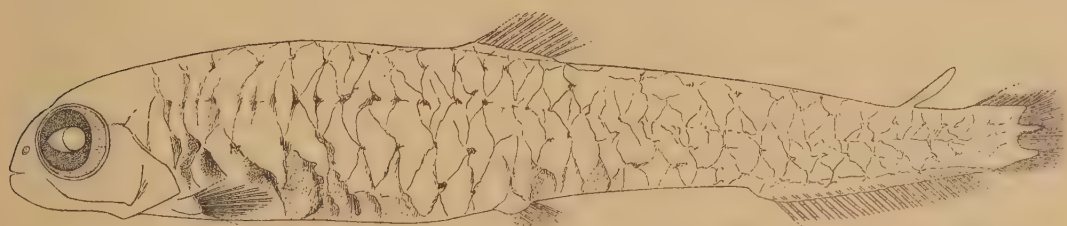


FIGURE 15. *Bathylagus bericoides*, 125.6 mm SL, OREGON St. 1028, Gulf of Mexico, 28°28'N, 87°18'W, CNHM. Drawn by Esther Coogle.

smaller ones, thereby approximately doubling the lateral-line scale count over the lateral scale-row count. Scales apparently extending as far forward as the interorbital region on top of head and onto upper part of opercle.

Head with dorsal profile curving gradually from nape to nostrils, thence falling almost vertically; ventral profile rising less steeply. Eyes relatively small, slightly convergent anteriorly, not projecting into dorsal profile of head. An orbital crescent absent or only very weakly developed. Interorbital space broadly concave, filled with translucent tissue. A series of nine well-defined pores running back from symphysis of mandibles.³⁶ Opercle bearing 4 or 5 weak, finger-like projections at its posteroventral corner. Gill opening above the fin base by a distance about equal to the length of that base; in specimens with gill opening undamaged, it does not extend beyond level of center of eye. Gill rakers compressed, their bases not closely pressed together; inner margins of rakers weakly serrate.

Both the premaxillary and the obliquely placed maxillary are slight bones, evidently loosely attached, as they are missing in many specimens examined.

Teeth small, pointed, in a single line on palatines and on head of vomer; about a dozen teeth on vomer and 5–10 on each palatine. Dentary teeth minute and compressed, giving the edge of the bone a serrate appearance. Tongue broad and spatulate, lacking teeth.

36. These are undoubtedly the structures termed "nine luminous spots on the mandible" in the original description.

Dorsal fin inserted ahead of midpoint of body. Dorsal adipose fin over posterior part of anal fin base. Anal fin base longer than length of caudal peduncle. Ventrals usually originating close to a vertical from posterior end of dorsal fin base.

Color. Margins of scale pockets very dark, especially along venter, the pockets lined with a purplish, faintly iridescent tissue which is evidently deciduous in nature, as it is absent from some scale pockets; indeed in most specimens only an occasional patch of it is present. All fins and head dusky.

Size. The largest specimen captured is 183.0 mm SL, taken off Bermuda.

Development. Several Pacific specimens of about 40 mm are relatively longer than adults and have a more generally dusky ground color and less pronounced scale pockets.

Habits. In the Atlantic, *B. bericoides* probably lives below 1000 m. Specimens have been captured in hauls between the surface and 1200 to about 1700 m, with the 1200-m specimen being taken in a closing net. Pacific specimens were captured at night between the surface and 100 m, suggesting that this species may carry out daily vertical migrations.

Relationships. Available material is insufficient to properly assess the status of the Atlantic and Pacific populations; for the present they are considered conspecific.

Range. Known from mid-North Atlantic, Bermuda, the Bahamas, a locality between Bermuda and the Bahamas, and the Gulf of Mexico. Specimens which appear to be of this same species have been taken at several localities in the north-temperate mid-Pacific.

Synonyms and References:

Scopelus bericoides Borodin, Proc. New England zool. Club, 10, 1929: 110 (orig. descr.; 41°30'N, 45°57'W, 0-800 fms.; type, MCZ 31627).

Melamphaes bericoides Borodin, Bull. Mus. comp. Zool. Harvard, 72 (3), 1931: 79 (classif., 33°N, 64°W, 1200-m net, closed).

Bathylagus bericoides Parr, Bull. Bingham oceanogr. Coll., 3 (7), 1937: 39, fig. 16 (descr., 24°51'N, 76°37'W, 8000 feet w.); Cohen, Breviora, Mus. comp. Zool., 98, 1958: 8 (Bermuda, Gulf of Mexico, 3 Pacific locals.: 39°31'N, 178°54'W; 39°08'N, 164°51'W; 42°16'N, 179°52'W).

Bathylagus microcephalus Springer and Bullis, Spec. Sci. Rep.-Fish., U.S. Fish Wildl. Serv., 196, 1956: 49; non Norman 1930 (28°28'N, 87°18'W, 780 fms.).

Family OPISTHOPROCTIDAE

Characters. Slender and subcylindrical or foreshortened and laterally compressed fishes. Pectoral fins inserted on sides. Ventral fin insertions variable. Dorsal adipose fin present or absent. Lateral line running straight back in midline of body, not continuing onto caudal fin. Scales cycloid, deciduous. Eyes tubular in all but *Bathylchnops*, directed anteriorly, dorsally, or dorsolaterally. Supraorbital bones absent. Interorbital space very narrow, the width less than half the depth of caudal peduncle. Photophores and other luminous tissue present in a number of species, often associated with the eye. Frontals fused; parietals separate in the midline; premaxillary much reduced or absent; postcleithra, mesocoracoids, opisthotic, and orbitosphenoid absent. Swim bladder present

or absent. Teeth on head of vomer and on palatines of some species; present or absent on dentaries. Branchiostegals 2 to 4.³⁷

Range. Bathypelagic fishes which are probably to be found around the world in tropical and temperate waters.

Remarks. The Opisthoproctidae are the most specialized representatives of their Suborder and should surely be counted among the most bizarre of all teleost fishes. Although they agree with most other argentinoids in their bathypelagic habits, they are probably deeper-dwelling forms. I know of no member of the family having been taken alive very close to the surface. A deeper bathymetric distribution helps to explain the value of tubular eyes and the consequent skeletal specializations which of necessity accompany such striking modifications. Most of the opisthoproctids have sacrificed accommodation, efficient focusing, and probably clear image formation for binocular vision and increased efficiency in light perception (53: 403-405; 54: 996).

Many of the opisthoproctid fishes lack swim bladders, yet neither the long slender types nor the shortened types appear to be particularly efficient swimmers. These midwater animals would thus seem faced with the problem of keeping afloat, a problem which may be partially solved in a number of species by the elongation of the paired fins.

The placement of the pectoral fins near the midline of the body and their nearly vertical insertion may indicate considerable maneuverability at the front end of the fish, probably a necessary trait in fishes with such small mouths.

Another character of interest is the tendency in some for the ventral fins to be high up on the sides, and in a few, forward as well. In these fishes (*Macropinna*, *Rhynchohyalus*, and *Dolichopteryx*, *Winteria*?) the ventrals may replace the steeply inserted pectorals as hydrofoils.

Finally, the orbital light organs found in many species deserve comment. In at least one genus³⁸ the fish can probably cover the light organ; for others we have no information. It seems logical to doubt, however, that a fish with extremely sensitive eyes would have them continually subjected to light from its own nearby photophores. The question of whether the orbital light organs serve as signals, as food lures, for lighting the environment, or for some other purpose must await additional information.

Genera. Six genera are recognized. The genus *Rhynchohyalus* unites two distinct evolutionary lines by combining the elongated head and orbital light organs of the attenuated, subcylindrical *Dolichopteryx-Bathylchnops* group with the foreshortened, compressed body of the *Opisthoproctus-Macropinna-Winteria* group.

Also, in young *Macropinna* the snout is longer, the dorsal fin is in a more forward position, and the ventral fin is more posterior than in the adult. In all of these features young *Macropinna*³⁹ resemble adult *Rhynchohyalus*. Other similarities between *Rhyn-*

37. I have examined alizarin preparations of *Opisthoproctus* and *Dolichopteryx*.

38. Grey (24: 89) has noted that the light organ of a specimen of *Ophthalmopelton* (= *Rhynchohyalus*) from Bermuda was visible when the fish was captured but has revolved downward since that time and is no longer visible.

39. Chapman (9: 512-513, figs. 60-61) has presented figures of *Macropinna* 12 and 16.5 mm long. Grey (24: 88) and Maul (33 [1946]: 62) have commented upon the apparent relationship between *Rhynchohyalus* and *Macropinna*.

chohyalus and *Macropinna* are the forward position of the vent, the restricted opercle, and the posteriorly projecting subopercle and preopercle.

*Opisthoproctus*⁴⁰ is another genus which, in the young particularly, shows a strong resemblance to *Rhynchohyalus*. Notable similarities are the long snout, the high position of the pectoral fins on the body, the elongation of the ventral fin, and the insertion of the ventral fin above the venter.

Only a single specimen of *Winteria* has been reported. It resembles *Rhynchohyalus* in having a hyaline snout, tubular eyes, and pectoral fins located far up on the sides of the body.

The most obvious similarities between *Dolichopteryx* and *Rhynchohyalus* are the elevated position of the pectoral fins, the presence of orbital light organs, the strongly produced ventral fins (in all but one species of *Dolichopteryx*), the long snout, the apparent absence of premaxillaries, and the obliquely placed maxillaries.⁴¹

Bathylchnops resembles *Rhynchohyalus* in most of the same ways in which *Dolichopteryx* resembles the latter. Especially striking are similar-appearing photophores below the eyes in the former two genera.

Key to Genera

- 1 a. Body foreshortened and laterally compressed, not subcylindrical or elongated.
 - 2 a. Belly normal, without a scale-covered, ventral sole.
 - 3 a. Eyes directed dorsally.
 - 4 a. Branchiostegals 4; anal fin inserted behind a vertical from posterior end of dorsal fin base; suborbital luminous organ present (sometimes revolved inwards). *Rhynchohyalus* Barnard 1925, p. 51.
 - 4 b. Branchiostegals 3; anal fin inserted ahead of a vertical from posterior end of dorsal fin base; no suborbital luminous organ.
 - Macropinna* Chapman 1939.
Monterey Bay, California; Gulf of Alaska to British Columbia; Kurile-Kamchatka Trench.⁴²
 - Winteria* Brauer 1901.
Gulf of Guinea.
 - 3 b. Eyes directed anterodorsally.
 - 2 b. Belly with a scale-covered, ventral sole. *Opisthoproctus* Vaillant 1888, p. 60.
- 1 b. Body subcylindrical and elongated, not laterally compressed.
 - 5 a. Vomerine teeth in two or more rows; adult lacking accessory orbital luminous tissue in addition to a photophore; vertebrae 40-52.
 - Dolichopteryx* Brauer 1901, p. 53.

40. Schmidt (44: 29, fig. 19) has figured a specimen of *Opisthoproctus* 14 mm SL.

41. Chapman (10: 272), Grey (24: 87), Hubbs (26: 96), and Cohen (13: 47) have all suggested and, in some instances, given reasons for placing *Dolichopteryx* with the argentinoid fishes rather than in the Alepocephalidae where it had been placed by several earlier authors.

42. See Bradbury and Cohen (8: 57, fig. 1) for a figure and records of *Macropinna microstoma*, the only species in this genus.

- 5b. Vomerine teeth in a single row; adult with accessory orbital luminous tissue in addition to a photophore; vertebrae 80-84.

Bathylchnops Cohen 1958.
North Pacific between the Aleutian
and Hawaiian islands.

Genus *Rhynchohyalus* Barnard 1925

Rhynchohyalus Barnard, Ann. S. Afr. Mus., 21 (1), 1925: 130; NOMEN NOVUM PRO *Hyalorhynchus* Gilchrist and von Bonde 1924, preoccupied by Ogilby 1910, for bony fishes; type species, *Hyalorhynchus natalensis* Gilchrist and von Bonde 1924; takes the same type species. Off Table Bay, South Africa.

Generic Synonyms:

Hyalorhynchus Gilchrist and von Bonde, Rep. Fish. Mar. biol. Surv. S. Africa (1922), 3 (Spec. Rep. 7), 1924: 4, pl. 1, fig. 1; type species by monotypy, *Hyalorhynchus natalensis* Gilchrist and von Bonde 1924; NON *Hyalorhynchus* Ogilby 1910 for bony fishes. Off Table Bay, South Africa.

Ophthalmopelton Maul, Bol. Mus. Municipal Funchal, 2 (3), 1946: 62, fig. 23; type species by original designation, *Ophthalmopelton macropus* Maul 1946. Madeira.

Characters. Body strongly compressed laterally. Belly somewhat flattened, but without a sole. Eyes directed dorsally. Branchiostegals 4. Gill membranes broadly united and separate from isthmus. Suborbital light organ present. Premaxillaries apparently lacking. Dorsal adipose fin present. Ventral fins elongated, originating a short distance beyond the midpoint of body. Anal fin origin behind a vertical from posterior end of dorsal fin base. Anus between bases of ventral fins.

Range and Species. The single species in the genus is known from three specimens, one taken at Bermuda in a net hauled at 300 fathoms, another found in the stomach of a tuna at Madeira, and the third captured at 135 fathoms off Table Bay, South Africa.

Rhynchohyalus natalensis (Gilchrist and von Bonde) 1924

Figure 16

Study Material. One specimen from Bermuda, CNHM.

Description. Measurements in millimeters followed by per cent of standard length in parentheses, based on one specimen, 91.1 mm SL.

Body: depth at dorsal fin 20.2 (22.2); width behind head 10.5 (11.5).

Caudal peduncle: least depth 9.4 (10.3); length 9.5 (10.4).

Head: length 34.5 (37.9).

Eyes: greatest visible diameter of lens 5.1 (5.6); height 8.9 (9.8); distance between 1.5 (1.6).

Distance from tip of snout to: anterior edge of eye lens 18.8 (20.6).

Suborbital black area containing photophore: horizontal diameter 6.6 (7.2).

Fin base: dorsal 14.4 (15.8); anal 7.0 (7.7).

Distance from tip of snout to: origin

of anal fin 74.0 (81.2); origin of dorsal fin 56.5 (62.0); base of pectoral fin 36.5 (40.1); base of ventral fin 49.5 (54.3).

Distance from vent to anterior edge of: anal fin base 23.0 (25.2).

Lateral-line scales: 41.⁴³

Gill rakers: on first arch 6 + 17.⁴⁴

Branchiostegal rays: 4.⁴⁴

Fin rays: dorsal 12; anal 10; pectoral 19; ventral 11–12 (?).

Body strongly compressed, its dorsal profile rising abruptly above the opercle, then curving gently to origin of dorsal fin, thence descending at an angle of 16–18° to the deep caudal peduncle; ventral profile tapering only very slightly to base of anal fin, which is set off from body. Belly between head and origin of anal fin flattened.

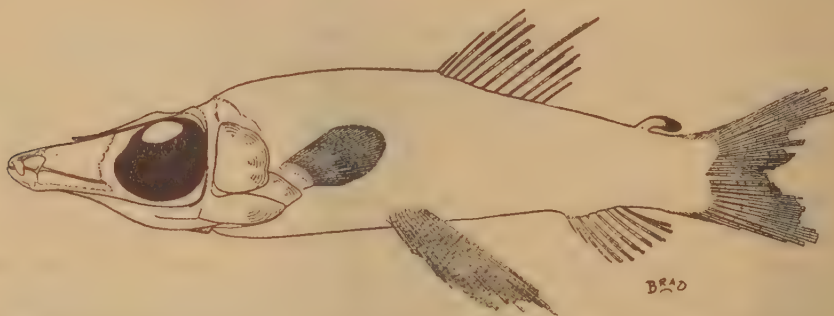


FIGURE 16. *Rhynchohyalus natalensis*, 94 mm SL, Bermuda, 37°02.2'N, 64°57'W, CNHM 49560. From Grey (24).

Head deepest at level of eye. Snout narrow and elongated. Eyes tubular, directed dorsally and separated by a very narrow interorbital space; the entire anteroventral segment, viewed from the side, covered by a black pouch which showed a distinct light organ at the time the fish was captured⁴⁵ but which has since turned inwards and is no longer visible. Opercle a short, scale-like bone extending ventrally only as far as base of eye. Subopercle sending a posterior projection to a point below posterior tip of pectoral fin base. Preopercle running forward to anterior edge of eye.

Mouth very small and terminal. Maxillaries thin, obliquely placed.

Teeth on head of the vomer in a row several teeth wide. Dentaries seemingly without teeth.

Dorsal fin originating closer to base of caudal than to snout, its base slightly longer than twice the length of the anal fin base. Dorsal adipose fin behind a vertical from posterior end of anal fin base. Anal fin origin behind posterior end of dorsal fin base. Pectoral fin on side of body about midway between lateral line and belly, inserted immediately above posterior projection of subopercle at an angle of about 30° from a plane parallel to the venter, its longest rays extending slightly past base of ventral fins. Ventral fin originating a short distance beyond midpoint of body, slightly above the venter, its longest rays extending beyond origin of anal fin.

43. From Gilchrist and von Bonde, on a specimen from South Africa (22: 4).

44. From Maul, on a specimen from Madeira (33 [1946]: 62).

45. See footnote 38.

Vent between bases of ventral fins, well in advance of anal fin. Body cavity, containing the gut, extending beyond vent, the gut swinging downward and forward, arriving at the vent from the posterior section of body.

Color. Body of a preserved specimen brown, with black pigment cells scattered on lower half. Ventral fins, bases of caudal fin, the dorsal fin, and the area around vent black. Head translucent, with the exception of eye tube, which is black. Shortly after preservation the body was white with some duskiness, the cheeks and opercles silvery (24: 89).

Range. See p. 51.

Genus *Dolichopteryx* Brauer 1901⁴⁶

Dolichopteryx Brauer, S.B. Ges. Beförd. ges. Naturw. Marburg, 8, 1901: 127; type species, *Aulostoma longipes* Vaillant 1888, by subsequent designation of Jordan, Leland Stanford Univ. Publ., Univ. Ser., 4, 1920: 492.⁴⁷ Coast of Morocco.

Characters. Body slender, subcylindrical anteriorly, slightly compressed behind. Belly lacking a sole. Luminous organs present in some species. Eyes tubular and directed dorsally. A light organ on eye tube. Branchiostegals 2. Gill membranes broadly united and separate from isthmus. Premaxillaries lacking.⁴⁸ Maxillaries easily lost; thin, scale-like, obliquely placed bones. Swim bladder absent. Dorsal adipose fin present or absent. Ventral, dorsal, and anal fins all posteriorly placed; dorsal and anal fins elevated from the body, paired fins on peduncles. Anus in a posterior position close to anal fin.

In all specimens examined and in figures of others, the ventral musculature of the body wall is absent; thus the gut is enclosed ventrally by only a transparent layer of skin and the transparent peritoneum. This ventral muscle separation continues posteriorly beyond the termination of the gut as far as the anterior procurent rays of the ventral lobe of the caudal fin. In addition, there is a shallower, distinct dorsal cleavage between the epaxial muscle masses of the two sides.

Remarks. Of the known opisthoproctid genera, *Dolichopteryx* seems most closely related to *Bathylychnops*. The nature of several of the differences between the two strongly suggests that *Dolichopteryx* is in certain respects neotenic. The occurrence of mature gonadal tissue in several specimens of *Dolichopteryx* shows that *Bathylychnops* is not merely an adult *Dolichopteryx* (16: 147).

Habits. *Dolichopteryx* consists of rare and fragile bathypelagic fishes of which only about 20 have been recorded in the literature. The species are probably restricted to

46. Roule and Angel (40: 69, pl. 4, figs. 90-98) have described several species of *Dolichopteryx* under the collective term *Dolichopterygiella*. Although they do not propose it as a generic name they imply its equivalence with *Dolichopteryx* Brauer, and they utilize the trivial names proposed by Vaillant and Brauer.

47. Jordan stated that *Dolichopteryx longipes* Brauer was the orthotype ("the type of a genus as indicated or distinctly implied by the original author") of *Dolichopteryx*. In so doing he erred doubly. First of all, Brauer is not the author of *D. longipes*. Secondly, in his original description of *Dolichopteryx*, Brauer placed his new species, *D. anascopa*, and also *Aulostoma longipes* Vaillant in the new genus; however, Brauer in no way indicated or implied a type species. In spite of these errors I see no reason why Jordan's type designation should not stand.

48. Cohen (13: 47) has pointed out that the bone in this fish called the premaxillary by some authors is actually the head of the vomer.

depths greater than 350 m; one has been taken in a closing net at a depth of 2500–2700 m. The elongated filamentous fins and the reduced musculature of these fishes make it appear probable that they are poor swimmers.

Range. Probably world-wide in tropical and temperate seas. Specimens are known from the tropical Atlantic; off Capetown, South Africa; the eastern Indian Ocean; California; and the Galapagos Islands.

Species. Opinions differ as to whether there is but a single variable species (34: 271) or at least four and possibly more species (35: 33). I am inclined to accept the latter opinion.

Key to Species

- 1 a. Pectoral fin reaching less than half the distance from base of pectoral fin to origin of anal fin.
 - 2 a. Head 21 % of SL; greatest depth of body 9 % of SL.
brachyrhynchus Parr 1937, below.
 - 2 b. Head 29–32.4 % of SL; greatest depth of body 12.6–14.3 % of SL.
longipes (Vallant) 1888, p. 56.
- 1 b. Pectoral fin reaching more than half the distance from base of pectoral fin to origin of anal fin.
 - 3 a. Base of ventral fin closer to base of pectoral fin than to base of caudal fin.
anascopa Brauer 1901.
Indian Ocean, west of Cocos Islands.
 - 3 b. Base of ventral fin closer to base of caudal fin than to base of pectoral fin.
binocularis Beebe 1932, p. 59.

Dolichopteryx brachyrhynchus Parr 1937

Figure 17

Study Material. The holotype and only known specimen, in poor condition, BOC. The specimen is in such poor condition that the following account is based mainly on the original description.

Distinctive Characters. This species is distinguished by the combination of short pectoral fin, about seven luminous (?) bodies in the midventral line, posterior position of the anal fin, short head, short snout, and slender body.

Description. Proportional dimensions in per cent of standard length and counts taken from the original description of the holotype, 95 mm SL, from the Bahamas (35).

Body: greatest depth 9.0.

Head: length 21.0.

Snout: length 8.4.

Eyes: 4.7.

Fin length: pectoral 7.5.

Distance from tip of snout to: origin of anal fin 87.0; origin of dorsal fin 73.0; base of ventral fin 71.0.

Fin rays: dorsal 13; anal 12; pectoral 13; ventral 8.

Myomeres: about 70.

Body long, the greatest depth directly behind head, anteriorly almost as wide as deep, both the depth and width tapering only very slightly to the caudal peduncle. Light organs (?) in gelatinous material dorsally and ventrally; 6 or 7 median light organs ventrally in front of anal fin; another, possibly one of a pair, below pectorals;



FIGURE 17. *Dolichopteryx brachyrrhynchus*, 95 mm SL, holotype, Bahamas, 24°29'N, 75°53'W, BOC 2718. TOP, lateral view. BOTTOM, dorsal view. From Parr (35).

two pairs between ventral and anal fins. Four elongated, equally spaced dark bodies in the dorsal midline in front of dorsal fin; a similar structure on each side of dorsal fin base; and two median structures between dorsal and caudal fins.

Head excessively fragile, about as broad as its depth behind eye. Snout broad, and for a *Dolichopteryx* relatively short. Eyes tubular, slightly broader than wide. Lens protruding strongly from tube. A photophore in the tube of each eye, small and antero-laterally directed. Nostrils closer to tip of snout than to anterior edge of eye.

Teeth small, on dentaries and on head of vomer.

Dorsal fin base beginning slightly ahead of a vertical from posterior end of ventral fin base. Anal fin base beginning well behind a vertical from posterior end of dorsal fin base. Pectoral fins short, fan-shaped, originating on peduncles on lower half of body immediately behind head, placed at an angle of 60°. Ventral fins on peduncles having a very tenuous connection with body musculature, appearing to float almost free in the material surrounding the body.

Vent close to origin of anal fin.

Color. Aside from the pattern of light organs there is a distinct dark blotch on the base of the caudal fin and seven or eight faint, dusky transverse bars along the sides.

Development. The type is a mature male.

Reference:

Dolichopteryx brachyrhynchus Parr, Bull. Bingham oceanogr. Coll., 3 (7), 1937: 37, fig. 15 (orig. descr.; 24° 29' N, 75° 53' W, 7000 feet w., BOC 2718).

Dolichopteryx longipes (Vaillant) 1888

Figure 18

Study Material. Six specimens from the Bahamas, BOC.

Distinctive Characters. This species is set off from others of the genus by the combination of short pectoral fins, long ventral fins, a relatively large head, and absence of ventral light organs.

Description. Proportional dimensions in per cent of standard length, and counts, based on four Bahaman specimens, 70.4 to 79.5 mm SL. The mean first, followed by the range in parentheses.

Body: greatest depth 13.4 (12.6–14.3); greatest width 9.7 (9.2–10.0).

Caudal peduncle: depth 8.2 (7.8–8.7); length 14.1 (13.7–14.3).

Head: length 30.2 (29.0–32.4); width at eye 9.1 (8.5–10.0).

Snout: length 14.3 (13.9–15.0).

Eyes: lens diameter 4.3 (4.1–4.5); height from bottom of tube to top of lens 6.4 (5.9–6.8).

Fin base: dorsal 6.5 (6.4–6.8); anal 4.2 (4.0–4.4).

Distance from tip of snout to: origin of anal fin 84.7 (82.4–89.2); origin of dorsal fin 77.9 (75.8–82.1); base of ventral fin 71.8 (71.0–75.7).

Fin rays: dorsal 11 (10–11); anal 8–9; pectoral 13; ventral 8–9.

Myomeres: about 46.

Body deep, the greatest depth and width in the region of the pectoral fin base. Caudal peduncle more than half the greatest depth of body. Skin transparent, permitting observation of the myomeres, lateral-line nerve, and reduced body musculature. Muscles absent along entire ventral surface, thus exposing the gut through the skin and the transparent peritoneal membrane. Body musculature deeply cleft in the dorsal midline; a conspicuous dorsal cord of muscular tissue suspended between the epaxial muscle masses, running from posterior edge of skull to front of dorsal fin base, and from rear of dorsal fin base to anterior procurent rays of caudal's dorsal lobe. A similar cord running from the rear of anal fin base to the anterior procurent rays of caudal's ventral lobe.

Head gently tapering, about as broad as deep, both before and behind the eye. Snout appearing spatulate when viewed from above, its transparent dorsal portion membranous, roofed over for the most part by the delicate, elongated frontals; ventrally its bones are more translucent and carry some musculature. Skull with anterodorsal portion transparent. Brain visible both dorsally and laterally. Tubular eye obliquely placed in all specimens which I have examined, and the lens directed anterodorsally;

however, this may be an artifact as most illustrations show the eye placed vertically. A small black sac containing a photophore on lateral edge near the top of each eye tube; the photophore in one specimen directed anteroventrally, in the others ventrally, making it appear that the organ is movable, as it is in *Rhynchohyalus*. Bony inter-orbital composed of only the fused frontals, very narrow, measuring less than 1 mm across in any of the specimens examined. Nostrils raised on small papillae above posterior edge of maxillary. Bones of entire opercular apparatus reduced to a transparent membranous tissue. Gill openings extending more than halfway up the side of the fish.

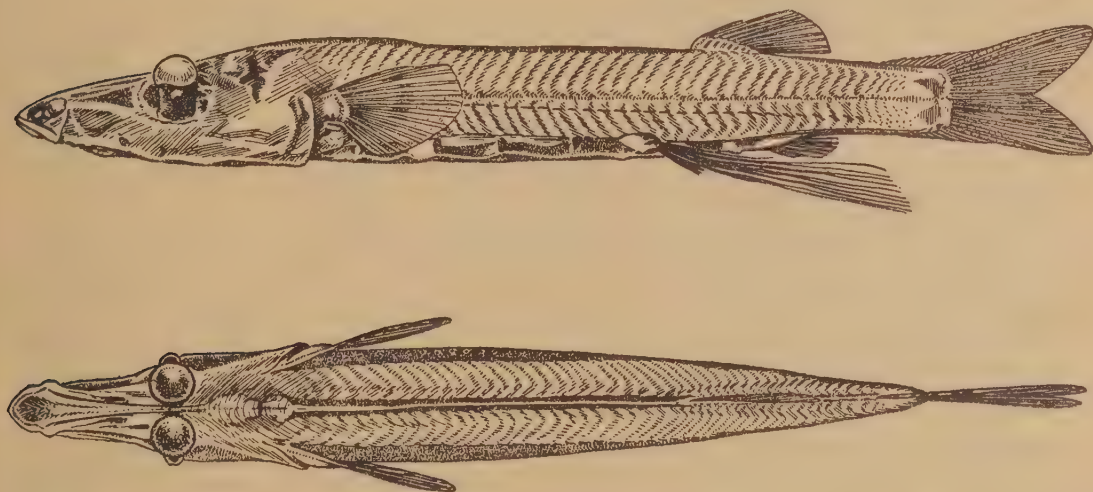


FIGURE 18. *Dolichopteryx longipes*. Bahamas, BOC. TOP, lateral view. BOTTOM, dorsal view. From Parr (35).

Mouth occupying less than 0.33 of the length of the snout, a prominent feature of the mouth being a retrorse knob projecting into it at the symphysis of the dentaries.

Teeth on dentaries in a single row, minute. The vomerine dentition is difficult to discern but it seems to consist of a band (6 or 7 teeth wide) of small, needle-like teeth.

Dorsal fin base beginning behind a vertical from the ventral fin base. A dorsal adipose fin has been reported for Bermuda and Galapagos specimens (24: 87-90), but I have seen none on the specimens at hand. Anal fin originating close to a vertical from posterior end of dorsal fin base. Dorsal and anal fin bases elevated from body, lacking muscular connection with the trunk; the paired fins on muscular peduncles, also not connected by muscles with the trunk. Pectoral fin shorter than half of head length, its vertically inserted peduncle high on the side of body, at about the level of the lateral line near the posterior margin of opercle. Ventral fins with triangular peduncles inserted at the ventral level of the body musculature, the entire width of gut between them, their rays elongated, usually reaching to base of caudal fin and sometimes beyond.

The gut, viewed ventrally, running straight back from between the pectoral fin

bases, where it emerges from under the liver and continues to the vent; viewed from the side, the ventral margin of gut projecting below ventral part of lateral musculature of body. A short distance behind the level of pectoral fins, four short pyloric caeca arise from the gut as does an elongated muscular fusiform body, thicker in its midsection than the intestine, this latter body terminating at a point about 80 % of the distance between bases of pectoral and ventral fins.

Color. A series of four pairs of evenly spaced blotches consisting of large, dark chromatophores in the lining of the ventral part of the peritoneal cavity on either side of the gut. A line of dark chromatophores along anterior side of body below lateral line to about the level of the dorsal fin, thence rearward, breaking up into obliquely placed groups of 5–10 chromatophores on each myomere; chromatophores scattered at posterior end of body. Two dark blotches at base of caudal fin, one above and one below the lateral line. Dorsal portion of snout above mouth dusky, as are the mandibles viewed ventrally. A poorly defined line with about a dozen large, dark chromatophores below the eye. Bases and rays of paired fins flecked with dark pigment. The gut, as viewed ventrally through the transparent membranes, without pigment.

Size. The largest known specimen is between 85 and 95 mm SL.⁴⁹

Development. The largest known specimen contained about 100 "well developed" eggs in each ovary. One specimen 35.5 mm SL contained a recognizable testicle; and the ovary of another, 46.2 mm SL, had small, unripe eggs (3: 72, 76, 77). I have seen two ribbon-like strands of eggs in a specimen 62 mm SL.

Habits. This is a deep-water pelagic species which has not been taken by nets fishing above 500 m and has been most often encountered below 1000 m.

Range. Known from the tropical North Atlantic. A specimen taken in the Pacific at the Galapagos Islands has also been identified as *D. longipes* (24).

Synonyms and References:

Aulostoma longipes Vaillant, Exped. Sci. "Travailleur" 'Talisman,' Poiss., 1888: 340, pl. 27, fig. 4 (orig. descr.; coast of Morocco, 1163 m, type in MNHN).

Dolichopteryx longipes Brauer, S.B. Ges. Beförd. ges. Naturw. Marburg, 8, 1901: 128 (*Aulostoma longipes* placed in *Dolichopteryx*); Brauer, Wiss. Ergebn. 'Valdivia,' 15 (1), 1906: 25 (*A. longipes* placed in *Dolichopteryx*); Jordan, Leland Stanford Univ. Publ., Univ. Ser., 4, 1920: 492 (*D. longipes* designated type species of *Dolichopteryx*); Beebe, Zoologica, N.Y., 16, 1933: 70, figs. 19–21 (descr., soft anat., ecol., ref., 4 specimens, 600–800 fms., Bermuda); Gregory and Conrad, Copeia, 1936: 25 (relations.); Parr, Bull. Bingham oceanogr. Coll., 3 (7), 1937: 35, fig. 14 (brief descr., synon., 25°55'N, 77°36'W, 5000 feet w.; 24°00'N, 77°16'W, 5000 feet w.; 23°42'N, 76°43'W, 7000 feet w.; 24°29'N, 77°29'W, 8000 feet w.); Grey, Copeia, 1952: 87 (descr., Galapagos Is., 300 fms.); Dollfus, Trav. Inst. Sci. Chérifien, Zool. 6, 1955: 29 (listed); Cohen, Stanford Ichthyol. Bull., 7 (3), 1958: 47 (osteol.).

Dolichopterygiella,⁵⁰ type *longipes* Roule and Angel, Résult. Camp. sci. Monaco, 79, 1930: 6, pl. 4, figs. 91–93, 96–98 (descr., relations., 29°16'N, 16°11'W; 31°32'N, 17°22'W; 31°45'N, 20°17'W; 30°45'30"N, 25°47'W).

Aulostomus longipes Bertin and Estève, Cat. Types Poiss. Mus. nat. Hist. nat., 6, 1950: 41 (type in MNHN).

Negative Reference:

Dolichopteryx longipes Norman, 'Discovery' Rep., 2, 1930: 271 (possibly *D. binocularis* Beebe).

49. See Parr (35: 35) for comments.

50. See footnote 46.

Dolichopteryx binocularis Beebe 1932

Study Material. The holotype, an alizarin specimen in glycerin, USNM.

Distinctive characters. This species is set off from other species of *Dolichopteryx* by the combination of elongated pectoral fin, about five luminous (?) bodies in the ventral midline, and the posterior position of the base of the ventral fin.

Description. Proportional dimensions in per cent of standard length, and counts, from the original description of the holotype, 85 mm SL, from Bermuda (3).

Body: depth 5.9.

Head: length 20.0.

Snout: length 12.0.

Eyes: diameter 3.6.

Fin lengths: pectoral 64.7; ventral

Lateral-line scales: 58.

Fin rays: dorsal 15; anal 11; pectoral 14; ventral 9.

Myomeres: about 58.

17.6.

Body slender, the greatest depth a short distance behind head, tapering very little to the caudal peduncle. Skin and peritoneum transparent along the length of venter, the gut showing through. Many small tubercles (luminous?) in a loosely suspended band of opaque tissue extending along the ventral surface of body.⁵¹ Scales thin, in a row along lateral line; also a second widely spaced row beneath lateral line on posterior portion of body; some also present behind opercles. Beebe (3) has described the lateral-line scales as follows:

The first scale, just above the base of the dorsal pectoral rays, is a well-ossified, thick, half circle, opening backward. The next 26 are very small, thin, slightly ossified and irregular, some almost straight, others three-fourths of-a-circle. The 27th scale occurs at 18.6 mm. in front of the dorsal. From here on the scales increase in size and thickness, and become circular. At the 40th, just over the ventral fins, they reach their largest size, the diameter keeping even for the succeeding scales to the last at the very base of the caudal. These are 86 mm. in outside, vertical diameter with a central oval opening .5 mm. in length. From the 40th on, the posterior rim of the central opening shows a slight thickening of osseous tissue, which concentrates toward the center until, in the 51st, a slight projection is visible. In the last five this extends clear across the central hole as a knob-shaped projection, and a low spine develops on the outside.

Tubular eyes obliquely placed, leaning forward at an angle of about 10° from the vertical. A black sac containing a posteroventrally directed photophore on the side of the tube. Nostrils closer to eye than to snout.

Mouth occupying about 33% of the length of snout. Dentaries lacking a retrorse knob at symphysis. Maxillary obliquely placed, wider and thinner posteriorly.

Teeth on dentary small, pointed, in a series. The vomerine teeth slightly larger and posteriorly directed.

Dorsal and anal fin bases elevated from body and lacking muscular connection with the trunk; the anal fin originating slightly ahead of a vertical from posterior end of dorsal fin base. The paired fins on muscular peduncles, also not connected by muscles with the trunk. Pectoral fin with upper 5 rays (6 according to Beebe, 3) prolonged

51. Tubercles no longer visible.

and filamentous, terminating near the midpoint of body, the 6th ray about half the head length, the remaining rays progressively shorter; the pectoral peduncle originating close to midline of body; the fin placed at an angle of about 50°. Ventral fins with triangular peduncles inserted at ventral level of body musculature, the width of the protruding gut between them, the rays broken, the bases very close to a vertical from anterior end of dorsal fin base. No evidence of an adipose fin.

Color. "The fish as a whole appears as a transparent white, with dark muzzle, five large, ventral blotches, and a midline of dark chromatophores."⁵²

References:⁵³

- ? *Dolichopteryx longipes* Norman, 'Discovery' Rep., 2, 1930: 271, fig. 3 (brief descr., 120 mm, 33°50' to 34°13'S, 16°04' to 15°49'E, 350-400 m; 100 mm, 5°30'N, 17°45'W, 2500-2700 m).
Dolichopteryx binocularis Beebe, Zoologica, N.Y., 13, 1932: 49, fig. 48 (orig. descr.; type USNM 170933; Bermuda, 400 fms.); Beebe, Zoologica, N.Y., 16, 1933: 59, figs. 16-18 (redescr. of type, osteol.); Gregory and Conrad, Copeia, 1936: 25 (relations.); Cohen, Stanford Ichthyol. Bull., 7 (3), 1958: 47 (osteol.).

Genus *Opisthoproctus* Vaillant 1888

Opisthoproctus Vaillant, Exped. Sci. 'Travailleur' 'Talisman,' Poiss., 1888: 105, pl. 14, figs. 1, 1a; type species by monotypy, *Opisthoproctus soleatus* Vaillant 1888. Coast of Morocco.

Generic Synonyms:

- Grimaldia* Chapman, Ann. Mag. nat. Hist., (11) 9 (52), 1942: 299; type species by original designation, *Opisthoproctus grimaldii* Zugmayer 1911; NON *Grimaldia* Chevreux 1889 for crustaceans.
Monacoa Whitley, Australian Zool., 10 (2), 1943: 171; NOMEN NOVUM PRO *Grimaldia* Chapman 1942, preoccupied by Chevreux 1889, for crustaceans; type species *Opisthoproctus grimaldii* Zugmayer 1911; takes the same type species.

Characters. Body foreshortened and laterally compressed. Ventral surface flattened, forming an elongated fusiform sole that reportedly acts as a reflector for a light organ inside the body near the anus (5: 862, fig. 1). Scales large, deciduous, cycloid, covering the sole as well as the body. Eyes tubular and directed dorsally, only the lenses visible when viewed from above; cradled in suborbitals and postorbitals and topped with gelatinous transparent tissue. Bony interorbital area reduced to a thin sliver. Brain plainly visible through transparent roof of skull behind eyes. No photophore on eye tube. No suborbital light organ. Branchiostegal rays 2. Premaxillary absent.⁵⁴ Maxillary a scale-like bone, easily lost. Dentary scoop-like, lacking teeth, occupying almost half the length of snout. Nasal capsules easily visible in the transparent material on dorsal part of head. Nostrils paired, elevated on papillae supported by nasal bones running on the median side of each capsule. Swim bladder present.⁵⁵ Adipose fin midway be-

52. A more detailed account is given in the original description, from which the above summary is quoted.

53. Parr (35: 34) has suggested that the specimen referred to *Dolichopterygiella*, type *anascopa*, by Roule and Angel (40: 73, pl. 4, figs. 94, 95) is probably identical with *D. binocularis* Beebe. This specimen seems, however, to represent an undescribed species, as its fin placement differs from that of *D. anascopa* Brauer and its color pattern differs from that of *D. binocularis*.

54. I agree with Chapman (10: 300) that several authors who have described a premaxillary in *Opisthoproctus* were actually seeing the vomer.

55. Bertelsen's (5: 862, fig. 1) and my own observations.

tween rear end of dorsal fin base and caudal fin base. Dorsal fin base slightly elevated in some specimens. Pectoral fins on peduncles on side of body, slightly closer to sole than to lateral line, their bases placed at an angle of 60° or more. Dorsal and ventral fins originating behind midpoint of body. Ventral fins at lateral edges of the sole along ventral outline of body. Caudal fin broad-based, deeply forked. Anus at posterior end of sole. Lateral line running straight back in midline of body to caudal peduncle; not reaching base of caudal. Opercle a vertically elongated bone, about three times higher than wide. Preopercle an L-shaped bone, its ventral arm extending far forward, beyond front of vertical from eye. Cleithrum sending an arm forward under the head, serving as a support for the sole. Urohyal projecting downward from ventral surface of head and attaching to a muscular mass⁵⁶ near the anterodorsal corner of the sole. Suborbital greatly expanded, shielding the side of eye and cheek. Metapterygoid reduced.⁵⁷

Remarks. Roule (37: 175) suggested that perhaps specimens were teratological examples of a species which normally resembled *Winteria*. Later he sadly rejected his hypothesis (39: 5), as a considerable number of *Opisthoproctus* had been recorded while only a single example of *Winteria* was known.

Parr (35: 27) has also considered the strange body form of these fishes and has suggested that the minimal amounts of vitamin D thought to be present at great depths might place a premium on poorly ossified fishes with low requirements of this compound.⁵⁸

Habits. *Opisthoproctus*, a pelagic form, is generally restricted to depths greater than about 200 m. The curious, ventrally directed light-reflecting apparatus which would seem to produce a low intensity of diffuse light can perhaps be correlated with the dorsally directed eyes. It may serve to facilitate interspecific recognition while minimizing the probability of detection by predators having laterally directed eyes (5: 862, fig. 1). Additional evidence that this organ aids in specific recognition is the presence on the soles of the two species of different pigment patterns which undoubtedly cause different light patterns when the photogenic organs are in action. Of the nine specimens of this genus examined, the only one which failed to show the sole pattern typical for its species was the smallest (22.6 mm SL), which undoubtedly was sexually immature.

Few precise data on depth of capture are available; however, rough estimates indicate that *O. grimaldii* and *O. soleatus* may have different depth preferences. The silvery colored *O. grimaldii* has been taken most often in the approximate depth range of 200–600 m while the darker-colored, larger-eyed *O. soleatus* is most often found below about 400 m. The depth distributions of the two species overlap, and they are sympatric in parts of their ranges (in several instances both species have come out of the same net), so that the idea of the light-reflecting apparatus as an isolating mechanism is applicable.

56. Identified as the coracohyoid muscle by Trewavas (50: 608).

57. I confirm Parr's (35: 31) observation that Trewavas (50: 607) has omitted the true metapterygoid and has mislabeled the entopterygoid as the metapterygoid.

58. Marshall (32: 324) has criticized and further discussed this idea.

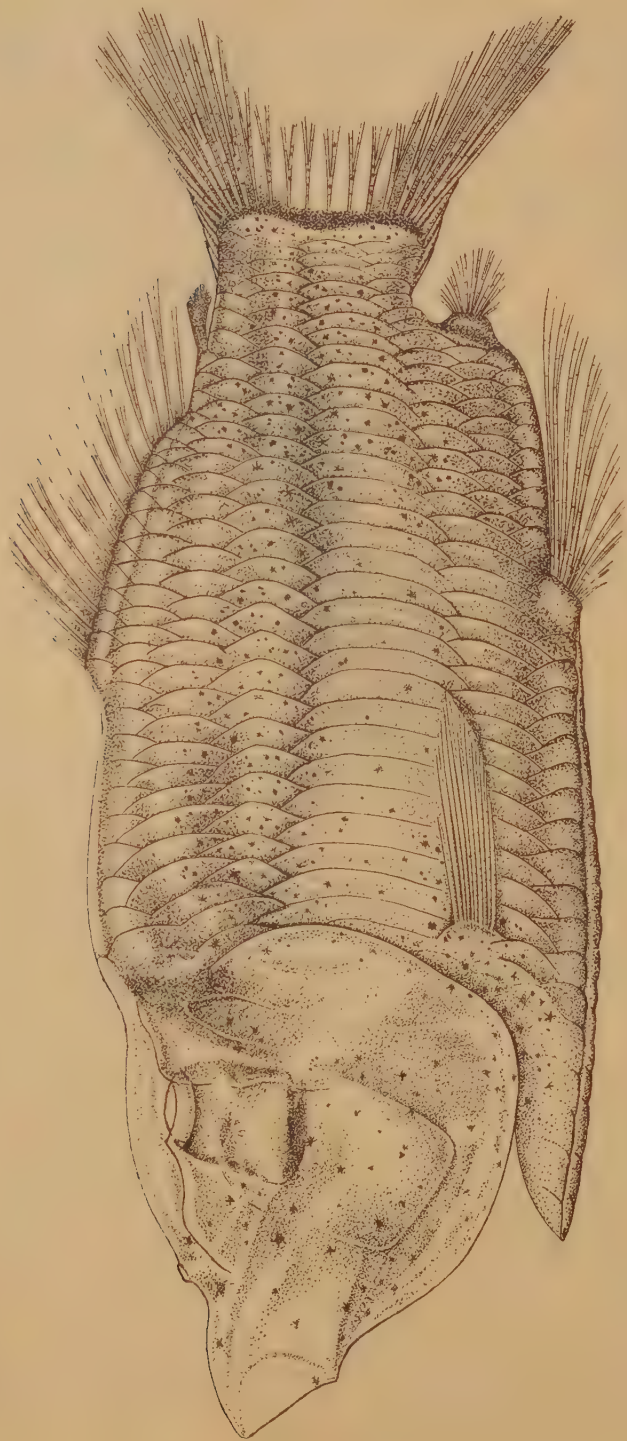


FIGURE 19. *Opithoproctus grimaldii*. Drawn from two specimens: 51 mm SL, $21^{\circ}20'N$, $71^{\circ}13'W$, BOC 3757; and 52.4 mm SL, $25^{\circ}35'N$, $79^{\circ}25'W$, UMMI. Drawn by Mildred Carrington.

Range. The genus is known chiefly from specimens captured in temperate and tropical waters of the North Atlantic. It has also been taken from the South China Sea, off Hawaii, and off California.

Species. Two species have been described and are placed in separate genera by some authors. *O. grimaldii*, the least modified of the two, has a relatively well-developed anal fin, a longer snout, a smaller eye, and a less pronounced sole. Apparently both nominal species are extremely variable in proportion and general appearance (41: pl. 2, figs. 16-23), so much so that one is led to believe that perhaps additional species should have been described. I have examined one specimen from Hawaii which is close to *O. soleatus* but may represent a distinct form.

Key to Species

- 1 a. Anal fin easily visible, not closely appressed to the caudal fin or caudal peduncle; posterior half of sole with four dark blotches. *grimaldii* Zugmayer 1911, below.
- 1 b. Anal fin rudimentary or absent, often closely appressed to caudal fin or caudal peduncle and not visible without dissection; posterior half of sole uniformly pigmented. *soleatus* Vaillant 1888, p. 65.

Opisthoproctus grimaldii Zugmayer 1911

Figure 19

Study Material. Two specimens: 1, 51 mm SL, from 21°20'N, 71°13'W, BOC; 1, 52.4 mm SL, 25°35'N, 79°25'W, UMML.

Distinctive Characters. This species is identifiable by an easily discernible anal fin.

Description. Proportional dimensions in per cent of standard length, and counts, for the 51-mm specimen first and the 52.4-mm specimen second.

Body: greatest depth 43.2, 45.4.
Caudal peduncle: depth 16.7, 17.6.
Head: length 44.3, 43.0.
Eyes: diameter of lens 6.9, 7.3;
 height 10.8, 11.8.

Distance from tip of snout to: anterior
 edge of eye tube 18.6, 17.2

Fin base: dorsal 25.5, 24.8; anal
 3.9, 3.8.

Fin length: pectoral 21.8, 19.5; ven-
 tral 22.5, 23.9.

Distance from tip of snout to: origin
 of anal fin 91.4, 92.0; origin of dorsal
 fin 60.8, 61.5; base of pectoral fin 45.2,
 42.4; base of ventral fin 68.6, 64.9.

Sole: length 73.0, 77.9; width 14.7,
 15.6.

Scale rows on sole: about 22.

Fin rays: dorsal 14, 14; anal 8, 8;
 pectoral 11, 11; ventral 10, 10.

Body relatively deep, the deepest part immediately behind head, where there is a pronounced hump in the dorsal profile, which then curves gently to the deep caudal

peduncle. Sole on the ventral surface broad, flat, scale-covered, running straight back from a point beneath eye to the vicinity of ventral fins, thence curving gently upward to its termination at the vent; its widest part about twice the body width above the lateral line, in front of the dorsal fin, thus giving the body a triangular cross section; viewed ventrally, the sole occupies most of body length, with only the caudal and anal fins and the anterior portion of the head visible at the ends. The widest part of the sole is slightly in advance of its midpoint.

Head tilted up in both specimens at hand; the snout directed forward and upward at an angle of about 45° ; the eyes directed somewhat posterodorsally; and the suspensorium tilted forwards at an angle of about 30° from the vertical. This condition may be an artifact. Snout elongated, beak-like, in the form of a translucent, projecting tube jutting out from beneath the eye, encompassed dorsally for part of its length by the transparent tissue covering the dorsal part of head. Tubular eye less in both diameter and height than length of snout. Nostrils protruding prominently about 33 % of the distance between eyes and tip of snout. First gill arch with about 20 small, widely spaced rakers.

Teeth small, pointed, 6 or 7 on head of vomer. No other teeth evident.

Anal fin on a vertical at posterior end of the sole, short-based, with all of its rays directed posteriorly. Ventral fins prolonged, their longest rays reaching beyond vent in both specimens.

Color. The ventral two-thirds of body and ventral part of head peppered with large dark chromatophores; dorsal part of head transparent; ventral part of body dark, as is the area between ventral and anal fin bases. Fins bearing scattered chromatophores, excepting the adipose, which is solid dark brown. Viewed ventrally, anterior part of sole with many scattered brown chromatophores, the silvery lining of the organ readily discernible through it; posteriorly, four transverse, dark blotches extending across the sole; the most anterior blotch with its posterior margin at about the midpoint of the sole; the second blotch with its posterior margin a short distance in front of ventral fin base; the third with its posterior margin midway between the origin of the ventral fin base and vent; the last located directly in front of vent. The lenses of one specimen pea green.

Size. The largest specimen on record is one of 60 mm taken by the Prince of Monaco off Portugal.

Development. A figure and brief description of a specimen 14 mm SL (44: 29, fig. 19) indicate a number of growth changes. In contrast with an adult, this small specimen has a more elongated snout, a less strongly developed sole, the vent farther forward, the ventral fins more strongly produced, and the base of the anal fin placed horizontally rather than vertically. In some of these characters young *O. grimaldii* resemble adult *Rhynchohyalus*. Another juvenile character is a dark, transverse bar between the lateral line and dorsal fin base.

Food. The stomach of one specimen was packed with the tentacles and nematocysts of siphonophores.

Range. Known in the eastern Atlantic from a number of localities in the area bounded by the Azores, the Canary Islands, and the Gulf of Cadiz. Taken off the Bahamas in the western Atlantic.

Synonyms and References:

Opisthoproctus grimaldii Zugmayer, Bull. Inst. océanogr. Monaco, 193, 1911: 2 (orig. descr.; 36°10'N, 11°48'W, types in MOM); Zugmayer, Résult. Camp. sci. Monaco, 35, 1911: 13, pl. 1, fig. 5 (more complete descr. of types); Murray and Hjort, Depths of Ocean, 1912: 90, 602, 611, figs. 73, 452 (35°32'N, 7°07'W; 29°08'N, 25°16'W; deeper than 500 m, taken in net with *O. soleatus*, *Gigantocypris*, and *Aceratias macrorhinus indicus*); Roule, Bull. Mus. Hist. nat. Paris, 21, 1915: 175-178 (cf. *O. soleatus*, relations, new Order, Platygastrichthyes, proposed); Schmidt, Rep. Danish oceanogr. Exped. Medit. 1908-1910, 2 Biol. A 5, 1918: 29, fig. 19 (descr., 35°53'N, 7°26'W, 600 m. w.); Gregory, Trans. Amer. philos. Soc., N.S. 23 (2), 1933: 151, fig. 43 (skull, cf. *Ctenothrissa*); Roule and Angel, Résult. Camp. sci. Monaco, 86, 1933: 35, pl. 2, figs. 20-23 (1 specimen SW. of Madeira, 1 specimen from Azores; cf. *O. soleatus*, revis. of species, variabil.); De Buen, Notas Inst. Español Océanogr., (2) 88, 1935: 47 (listed); Fowler, Bull. Amer. Mus. nat. Hist., 70 (1), 1936: 238, fig. 111 (descr. and fig. from Zugmayer, refs.); Parr, Bull. Bingham oceanogr. Coll., 3 (7), 1937: 33 (21°44'N, 72°43'W, 7000 feet w.; 21°20'N, 71°13'W, 6500 feet w.); Lozano Rey, Mem. Acad. Cien. Madrid, Ser. Cien. Nat., 11, 1947: 145, fig. 34 (descr., distr.); Belloc, Bull. Inst. océanogr. Monaco, 958, 1949: 9 (type in MOM, refs.); Albuquerque, Portug. Acta Biol., (B) 5, 1954-1956: 303, fig. 160 (descr., refs.); Marshall, Aspects of Deep Sea Biol., 1954: 230 (stomach contents of siphonophore tentacles and nematocysts); Dollfus, Trav. Inst. Sci. Chérifien, Zool. 6, 1955: 32, 106 (listed, refs.).

Grimaldia grimaldi Chapman, Ann. Mag. nat. Hist., (11) 9 (52), 1942: 299 (new genus proposed).

Monacoa grimaldii Whitley, Australian Zool., 10 (2), 1943: 171 (new name for *Grimaldia*, preoccupied).

Opisthoproctus soleatus Vaillant 1888

Figure 20

Study Material. Eight specimens: 5 from the Bahamas, BOC; 1 from 39°45'N, 71°08'W, WHOI; 1 (in alizarin) from Bermuda, SU; and 1 from Hawaii.

Distinctive Character. The anal fin is apparently absent or else reduced to a small splint.

Description. Proportional dimensions in per cent of standard length, and counts, for four Bahaman specimens, 44.8 to 54.6 mm SL. The mean first followed by the range in parentheses.

Body: greatest depth 38.1 (35.7-40.2); depth at base of caudal fin 17.4 (16.8-17.9).

Head: length 37.4 (35.3-38.6).

Eyes: diameter of lens 9.7 (9.2-10.9); height 15.1 (13.7-16.7).

Distance from tip of snout to: anterior edge of eye tube 12.6 (12.2-12.8).

Fin base: dorsal 15.6 (14.8-16.3).

Distance from tip of snout to: origin of dorsal fin 66.4 (65.0-68.3); base of

pectoral fin 41.1 (38.5-43.3); base of ventral fin 63.7 (59.1-68.1).

Sole: length 91.4 (87.8-95.6); width 17.9 (16.5-19.5).

Scale rows on sole: about 22.

Fin rays: dorsal 11 (10-12); pectoral 14; ventral 9 (9-10).

Vertebrae: 31 (one from Hawaii, one from Bermuda).

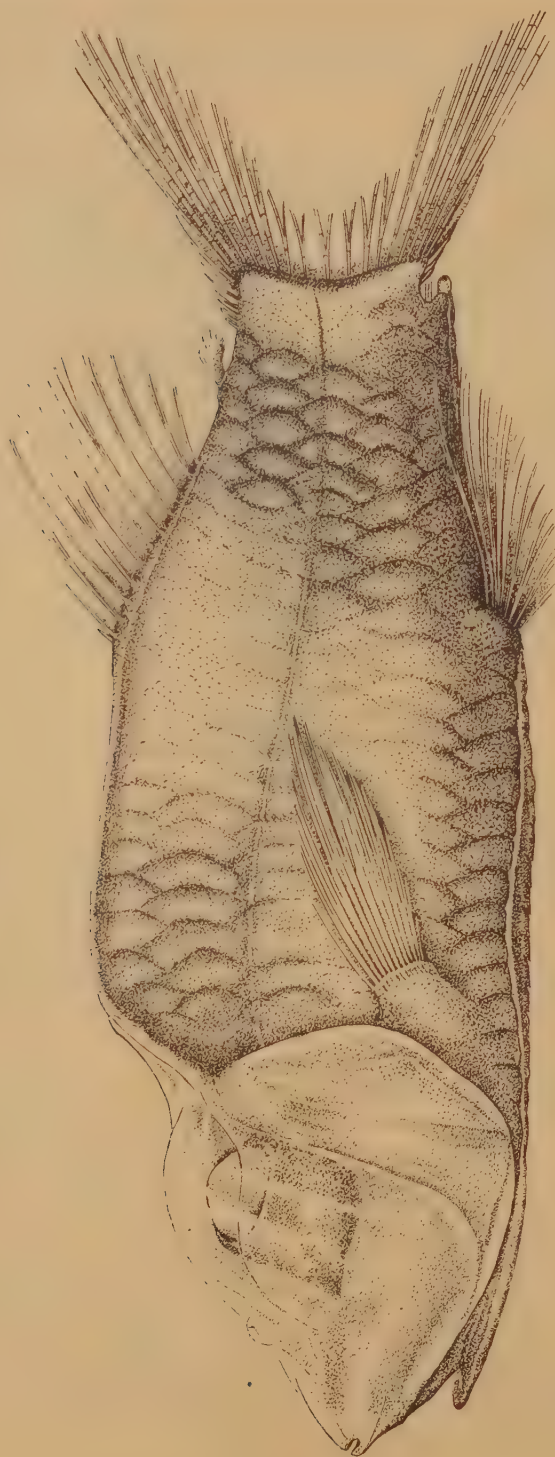


FIGURE 20. *Opisthoproctus soleatus*. Drawn from three specimens: 54.6 mm SL, 24°29'N, 77°28'W, BOC 2719; 45.9 mm SL, 24°00'N, 77°17'W, BOC 2724; 22.5 mm SL, 34°45'N, 71°08'W, WHOI. Drawn by Mildred Carrington.

Body elongated, with the deepest part immediately behind the head in some, half-way to the dorsal fin in others, its dorsal profile from origin of dorsal fin runs down and back at an angle of $25-30^{\circ}$. Sole on ventral surface broad and flat, beginning beneath snout, usually closer to anterior tip of snout than to eye and extending posteriorly to the vent, immediately below the base of caudal fin; the sole extending backward to the vent in a straight line in some specimens, but in others bending upwards at an inflection at the level of the ventral fins; its widest part, in advance of the midpoint, less than twice the body width above the lateral line, in front of dorsal fin.

Head variously tilted upwards in several of the specimens examined, this probably being a distortion, for in others the snout points straight ahead, the eyes straight up, and the ventral surface of the head nests snugly against the sole. Snout broad, rounded, short, its transparent dorsal profile falling from eye at an angle of $40-60^{\circ}$. Tubular eye greater in height than and about equal in diameter to length of snout. Nasal capsules prominent. Gill rakers small and stubby, about 12 on first arch of a specimen from Hawaii.

Teeth of Bahaman specimen minute and pointed, about 35 in a row across head of vomer. The Hawaiian fish with five teeth on left palatine and 2 or 3 on the adjacent area of vomer. The alizarin specimen from Bermuda has about 25 teeth in an irregular row across the head of vomer and about 5 on each palatine.

Anal fin not visible externally in some specimens; visible in others as 2 or 3 rudimentary rays protruding slightly behind vent.

Color. Sides of body dark. Head below and behind eye sprinkled with large, dark chromatophores; possibly silvery in life. Snout translucent ventrally, transparent dorsally. Anterior part of sole, viewed ventrally, bearing many scattered brown chromatophores through which the silvery lining may be seen. The sole posteriorly of a uniform dark color with no alternating blotches and light areas. The only exception is in the smallest specimen (22.5 mm) which has a uniformly light area.

Size. The largest specimen on record is 103 mm, taken east of the Azores by Prince Albert of Monaco.

Development. One of the smallest specimens known is the 22.5-mm fish reported upon here. It has a relatively deeper body, deeper caudal peduncle, longer head, snout, predorsal distance, and dorsal fin base than do larger examples.

Range. Known from the tropical and temperate North Atlantic, the farthest north at $48^{\circ}04'N$, southwest of Ireland; from the South China Sea; and from Hawaii, where specimens of what may be this species were taken dead at the surface during the Mauna Loa lava flow in 1950.

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- Opisthoproctus soleatus* Vaillant, Exped. Sci. 'Travailleur' 'Talisman,' Poiss., 1888: 105, pl. 13, figs. 1, 1a (orig. descr.; coast of Morocco, type in MNHN, placed in Maurolicidae); Goode and Bean, Smithson. Contr. Knowl., 30, 1895: 513, pl. 30, fig. 112 (comment, fig. from Vaillant); Garman, Mem. Mus. comp. Zool. Harvard, 24, 1899: 400 (listed); Brauer, S.B. Ges. ges. Naturw. Marburg (1901), 8, 1902: 115-130 (comments on eye); Brauer, Wiss. Ergebn. 'Valdivia,' 15 (1), 1906: 15, pl. 1, figs. 8-10 (descr., placed in Salmonidae); 15 (2), 1908: 208, pl. 4c, figs. 6-10, pl. 41, figs. 1-11 (histol. of eye); Murray and

Hjort, Depths of Ocean, 1912: 90, 94, 602, 611, fig. 72 (29°08'N, 25°16'W; deeper than 500 m, taken in net with *O. grimaldii*, *Gigantocypris*, and *Aceratias macrorhinus indicus*; 31°24'N, 34°47'W, night haul, about 600 m, taken in net with *Macrostomias longibarbus* and *Oneirodes*; 34°44'N, 47°52'W); Roule, Bull. Mus. Hist. nat. Paris, 21, 1915: 99-100, 175-178 (discus. X-ray of specimen; cf. *O. grimaldii*; relations.; new Order, Platygastrichthyes, proposed); Roule, Bull. Inst. océanogr. Monaco, 320, 1916: 7 (descr., 1 specimen E. of Azores); Schmidt, Rep. Danish oceanogr. Exped. Medit. 1908-1910, 2 Biol. A 5, 1918: 28, fig. 18 (descr.; 48°04'N, 12°40'W, 1 specimen 1000 m. w., 1 specimen 1800 m. w.; 35°53'N, 7°26'W, 1 specimen 1600 m. w.); Roule, Résult. Camp. sci. Monaco, 52, 1919: 21, pl. 5, fig. 3 (redescr. of Roule, 1915 specimen, relations.); Roule and Angel, Résult. Camp. sci. Monaco, 86, 1933: 35, pl. 2, figs. 16-19 (6 specimens from 2 locals. SE. of Madeira; cf. *O. grimaldii*, revis. of species, variabil.); Trewavas, Proc. zool. Soc. London, 1933: 601, pl. 2, text figs. 4-8 (South China Sea, anat., relations.); De Buen, Notas Inst. Español Océanogr., (2) 88, 1935: 47 (listed); Fowler, Bull. Amer. Mus. nat. Hist., 70 (1), 1936: 238 (descr. from Brauer, ref.); Parr, Bull. Bingham oceanogr. Coll., 3 (7), 1937: 33, figs. 9-13 (9 specimens from 6 locals. in the Bahamas, skel., notes swim bladder and poor ossif.); Beebe, Zoologica, N.Y., 22 (3), 1937: 201 (Bermuda, 450 fms.); Roule, Bull. Inst. océanogr. Monaco, 726, 1937: 1 (relations.); Bertin, Bull. Mus. Hist. nat. Paris, (2) 12 (6), 1940: 309 (type in MNHN); Lozano Rey, Mem. Acad. Cien. Madrid, Ser. Cien. Nat., 11, 1947: 143, fig. 33 (descr., distr.); Maul, Bol. Mus. Municipal Funchal, 4 (9), 1949: 19, fig. 7 (descr., refs., Madeira); Albuquerque, Portug. Acta Biol., (B) 5, 1954-1956: 302, fig. 159 (descr., refs.); Dollfus, Trav. Inst. Sci. Chérifien, Zool. 6, 1955: 32, 105 (listed, refs.).

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A REVIEW OF THE OPHIDIROID FISH GENUS *OLIGOPUS* WITH THE DESCRIPTION OF A NEW SPECIES FROM WEST AFRICA

By DANIEL M. COHEN¹

Introduction

This paper defines the genus *Oligopus*, presents a discussion of generic synonymy, and gives diagnoses of six species, one of which is described herein as new to science.

The species of *Oligopus* have numerous fin rays and small scales, as is true of many other ophidioids. Because the bases of the fin rays almost invariably are obscured by darkly pigmented skin, most counts of vertical fin elements were made from X-ray photographs. In addition, internal skeletal characters were observed only from X-ray photographs. Examination of the head pores was aided by the use of a compressed air jet.

These fishes secrete a thick mucous coat that often makes it difficult to count scales and to observe pores. Also, the papillae that mark

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the course of the lateral line are fragile structures which may be lost when the mucous coat is removed.

Following are the definitions of some of the terms and abbreviations used in this paper: Predorsal: shortest distance between tip of snout and a vertical through origin of dorsal fin; preanal: shortest distance between tip of snout and a vertical through origin of anal fin; SL: standard length; HL: head length; upper jaw: shortest distance between tip of snout and posterior margin of maxillary; greatest depth of maxillary: depth at posterior expanded region of bone, but not including downward projecting maxillary spine; greatest head width: width of head with opercular flap compressed; D: dorsal fin rays; A: anal fin rays; caudal fin rays: only those rays articulating with hypural plate; vertebrae: count not including hypural; lateral scale rows: counted from upper angle of opercle; head canals: terminology follows Robins (1959).

I have examined material deposited in the following institutions and I am much indebted to their respective curators: Academy of Natural Sciences of Philadelphia (ANSP); British Museum (Natural History) (BMNH); Museum of Comparative Zoology at Harvard University (MCZ); Rhodes University, Grahamstown, South Africa (RU); Scripps Institution of Oceanography (SIO); Stanford University, Division of Systematic Biology (SU); University of Bergen Zoological Museum (UBZM); University of Copenhagen Zoological Museum (UCZM); University of Hawaii (UH); U.S. National Museum (USNM); University of Puerto Rico (UP). Mr. Luis Rivas has furnished me with information concerning the type of *O. claudiei*. Mr. and Mrs. Craig Phillips have donated a specimen of *Stygnobrotula*. Dr. Frank H. Talbot and Mr. W. I. Follett X-rayed the type of *Eutyx diagrammus*. Mr. Jørgen Nielsen X-rayed the type of *Bythites fuscus*. Mr. Alwyne Wheeler X-rayed specimens in the British Museum. I particularly thank my colleagues I. Bruce B. Collette and Dr. Ernest A. Lachner for their advice during the course of this study and for their critical review of the manuscript.

Genus *Oligopus* Risso

- Oligopus* Risso, 1810, p. 142 (type species by monotypy *Oligopus ater* Risso, 1810).
Gadopsis (not Agassiz, 1845; not Richardson, 1848) Filippi, 1856, p. 170 (type species by monotypy *Oligopus ater* Risso, 1810).
Grammonus Gill in Goode and Bean, 1896, p. 315 (type species by monotypy *Oligopus ater* Risso, 1810).
Verater Jordan, 1919a, p. 343 (proposed as a replacement name for *Pteridium* Filippi and Verany, 1859; however, these authors used *Pteridium* Scopoli, 1777. Type species by original designation of Jordan *Oligopus ater* Risso).
Eutyx Heller and Snodgrass, 1903, p. 224 (type species by monotypy *Eutyx diagrammus* Heller and Snodgrass, 1903).

athystorreus Howell Rivero, 1934, p. 69 (type species by original designation *Benthocometes claudaei* Torre, 1930).

DIAGNOSIS.—Gill membranes separate. Chin barbel absent. Live-bearing. Pelvic fins each with one ray, originating close to level of posterior margin of preopercle and about an eye diameter behind symphysis of cleithra; vertical fins continuous, covered proximally with thick, scaleless skin; pectoral fin entire, without separate, elongated rays. Head partly naked, bearing dermal papillae; anterior nostril tubular, located directly above upper lip; gill rakers 2 or 3; tongue a massive structure with anterior, prowlike projection fitting between 2 heads of geniohyoideus muscle. Branchiostegal rays 8. Body relatively short, stubby; head not depressed, height greater than width. Lateral line with 2 or more series, dorsal and ventral sometimes overlapping or parallel for entire lengths; palatine lacking teeth; ventrally directed projection usually present at posteroventral section of maxillary; posterior portion of maxillary expanded. Eyes well developed. Body completely covered with small cycloid scales. Lining of peritoneum pale in color.

First neural spine low; neural spines 2, 3, 4 raised, followed by series of low neural spines with more or less truncate tops (fig. 1). Vertebrae 1 and 2 without ribs; vertebra 3 with pair of anteroventrally directed ribs; vertebrae 4–6 with posteroventrally directed ribs articulating with centra; vertebra 7 with ribs attached, free or at end of parapophyses; vertebrae 8–10, 11 or 12 with ribs at ends of parapophyses; all other vertebrae lacking pleural ribs.

RELATIONSHIPS.—*Oligopus* is a distinctive group of well-differentiated species. The genus apparently represents a rather generalized type of ophidioid, at least among the live-bearers, and this fact, along with its relatively shallow-water habitat, suggests that, together with *Bythites*, *Oligopus* may be close to the stem from which various forms descended toward an abyssal habitat while others colonized the coral reefs: *Oligopus* has affinities with fishes that dwell in both areas.

Among the reef inhabitants, *Microbrotula*, *Grammonoides*, and *Stygnobrotula* are related to *Oligopus*; the former two even possess the peculiar projection on the maxillary. None of the three genera, however, displays the peculiar shortened and truncate neural spines (fig. 1) that are characteristic of *Oligopus*; moreover, *Microbrotula* has palatine teeth, and Böhlke (1957) has given a number of reasons for separating *Stygnobrotula* from *Eutyx* (here considered a junior synonym of *Oligopus*), most of which serve to separate *Stygnobrotula* from the more inclusive genus *Oligopus*. Particularly important are Böhlke's items 1, 2, 3, 4, 6, 7, 9, and 13 of his table 1, p. 3, to

which the reader is referred.² *Grammonoides* is also different in dentition, lacking the bands of granular teeth on the premaxillary and the dentary.

Among the genera confined to deeper water, the closest relatives of *Oligopus* are those forms with a tubular anterior nostril placed directly over the upper lip, reduced squamation on the head, and a single ray in each ventral fin. This group includes *Diplacanthopoma*, *Myxocephalus*, the species presently assigned to *Cataetys* (at least two genera are included in this group), and *Bythites*. All of these differ from *Oligopus* in possessing palatine teeth, and in lacking shortened, truncate neural spines. In addition, *Diplacanthopoma* and *Myxocephalus* lack scales on the head. Most of the species of *Cataetys* (though not the type, *C. messieri*) have strongly depressed heads.

Oligopus ater, the type species of *Oligopus*, long has been considered congeneric with a superficially similar species that was described originally by Doderlein (1886) as *Pteridium armatum*. Bougis and Ruivo (1954) reported on specimens that they identified as *Benthocometes robustus*, a name that they treated as a senior synonym of *P. armatum*. They illustrated (their fig. 19) specializations of the anterior vertebrae that bear some resemblance to those long known to exist in the Ophidiidae (in the restricted sense), but there is some conflict in this identification, for Doderlein (1886) did not show modified anterior vertebrae in his figure of a dissection of *Pteridium armatum*. These structures, however, have been shown to be sexually dimorphic in the ophidiid genus *Ophidion* (Rose, 1961). Whatever the identity of *P. armatum*, *Oligopus* differs widely both from Doderlein's description and from *Benthocometes*. It is of interest to note that another species of *Oligopus* (*O. clauderi*) was also confused with *Benthocometes*.

The foregoing discussion is based on the material listed below.

MATERIAL EXAMINED.—*Benthocometes robustus* (USNM 2908, paratype); *Bythites fuscus* (UCZM, holotype); *Bythites lepidogenus* (USNM 74152, holotype); *Cataetys hawaiiensis* (USNM 16279, holotype); *Cataetys laticeps* (UBZM, holotype); *Cataetys messieri* (BMNH, holotype); *Diplacanthopoma brachysoma* (BMNH, holotype); *Diplacanthopoma brunnea* (USNM 74148, holotype); *Grammonoides opisthodon* (RU, holotype); *Microbrotula rubra* (USNM 16279, holotype); *Myxocephalus japonicus* (USNM 160604); *Stygnobrotula latebricola* (USNM 187777); *Xenobythites armiger* (USNM 7413, holotype).

SYNONYMY.—In his original description of *Oligopus ater*, Risso (1810) credited the genus *Oligopus* to Lacépède; however, Riss's

² Boeseman (1960) overlooked the description of *Stygnobrotula latebricola* and described the same species as *Eutys tumidirostris*.

spelling is an unjustified emendation of *Oligopodus* Lacépède, 1800, proposed for *Coryphaena velifera* Pallas, and therefore, *Oligopus* is available from 1810 with Risso as the author.

Swainson (1839) placed *O. ater* in *Pteridium* Scopoli, and Filippi (1856) proposed the generic name *Gadopsis* (already twice preoccupied) for the species. Filippi and Verany (1859) then accepted *Pteridium* Scopoli (proposed for *Coryphaena velifera* Pallas) for *O. ater* and have been followed by numerous authors. Gill (in Goode and Bean, 1896) proposed *Grammonus* for *Oligopus ater* Risso, with no comment.

Verater was first proposed by Jordan (1919a) as a substitute for *Pteridium* Filippi and Verany although these authors plainly indicated they were following Swainson, who used *Pteridium* Scopoli; however, in a later publication during the same year, Jordan (1919b) presented *Verater* as a replacement name for *Gadopsis* Filippi, with *O. ater* Risso as the type species.

Heller and Snodgrass compared *Eutyx* with *Grammonus* Gill and separated the two on the grounds that the former genus lacked an opercular spine, had a double lateral line, and had large muciferous canal openings on the head. Actually, *Eutyx* may have its small opercular spine hidden or exposed (Böhlke, 1957, and the present author); its lateral line (described below under *Oligopus diagrammus*) is similar to that in other species of the genus, and all of the species here referred to *Oligopus* have canal openings on the head.

Bathystorreus was proposed for a species originally described in *Benthocometes*, where it obviously did not belong. The single known specimen is in bad condition; however, an X-ray photograph showing the abdominal vertebrae gives reason enough to place this species in *Oligopus*.

SPECIES.—Six species are referred herein to *Oligopus*. Although the available material of most is limited, a few suggestions concerning relationships and distributions can be presented. *O. claudei* from the tropical western Atlantic is distinct from all other *Oligopus*. Distinct preopercular spines and numerous head pores are its distinguishing characters. *O. diagrammus* is known from Galapagos, Guadalupe, and lower Baja California. The material suggests the presence of a species complex or a group of subspecies. *O. diagrammus* has a reduced number of head pores but high fin ray and vertebral counts. Apparently it is most distantly related phylogenetically to the western Atlantic species. The other species are *O. longhursti* (herein described as new), known from tropical West Africa; *O. ater* from the Mediterranean; *O. robustus* from Japan, the Philippines, and the Indian Ocean; and *O. waikiki* from Hawaii. The latter, wide-ranging group of four species is intermediate phylogenetically as

well as geographically between the western Atlantic and the eastern Pacific species.

I do not consider *Grammonus leucos* Osorio, 1917, to be referable to *Oligopus*, as the original description mentions the presence of teeth on the palatines. Professor Fernando Frade has informed me that the type cannot be found in the Museu Bocage.

Key to Species of *Oligopus*

- 1a. One or no pores in lateral head canal system; 1 or 2 pores in supraorbital canal. Spines along preopercle margin absent or small and weak.
 - 2a. Dorsal fin rays 68-87; anal fin rays 51-62; vertebrae 40-46.
 - 3a. Dorsal fin rays 68-74; anal fin rays 51-52; vertebrae 40-42 . . . *O. ater*
 - 3b. Dorsal fin rays 83-87; anal fin rays 57-62; vertebrae 44-46.
 - 4a. Lateral scale rows about 120. Upper row of lateral line organ about 35-45; lower about 35-40; dip in ventral lateral line in ventral area *O. longhursti*
 - 4b. Lateral scale rows about 75-85. Upper row of lateral line organ about 21; lower row about 25-30; no dip in ventral lateral line. *O. robustus*
 - 2b. Dorsal fin rays 93-115; anal fin rays 71-91; vertebrae 48-53.
 - 5a. Lateral scale rows about 80; anal fin rays 71; 6 pores in infraorbital canal system *O. waikiki*
 - 5b. Lateral scale rows 97-115; anal fin rays 76-91; 5 or fewer pores in infraorbital canal system *O. diagramma*
- 1b. Three or 4 pores in lateral head canal system; 2, 3, or 4 pores in supraorbital canal. Several small but distinct spines along preopercle margin. *O. claudae*

Oligopus ater Risso

PLATE 2

- Oligopus ater* Risso, 1810, p. 142, pl. 11, fig. 41 (original description, Gulf of Saint-Hospice, France).—Fowler, 1936, p. 1329 (description, synonymy).
- Oligopus niger* Risso, 1826, p. 338 (new name for *O. ater* Risso, 1810; description).
- Pteridium ater* Swainson, 1839, p. 302 (*O. ater* Risso listed under *Pteridium* Scopoli).
- Gadopsis ater* Filippi, 1856, p. 170 (description of swim bladder, new genus proposed).
- Pteridium atrum* Filippi and Verany, 1859, p. 195, fig. 6 (synonymy, description of swim bladder, relationships).—Doderlein, 1886, p. 73 (comparison with *Pteridium armatum*).—Günther, 1887, p. 105 (description, 1 specimen from Mediterranean).—Bellotti, 1888, p. 222 (sexual dimorphism in dentition of specimens from Nice and nearby, comparison with *Pteridium armatum*).—Lo Bianco, 1909, p. 741 (pelagic postlarvae circa 30 mm., January, February, March, in Gulf of Naples).—D'Ancona, 1938, p. 159, figs. 2, 4, 8 (comparison with *P. armatum*, description, based on material from Nice, Naples, and Zirona, nomenclature, relationships, distribution, additional references not here cited).
- Grammonus ater* Goode and Bean, 1896, p. 317 (new genus proposed, synonymy, compiled description).—Tortonese, 1958, p. 333 (listed, doubts that *G. ater* (Risso) and *G. armatus* (Doderlein) belong in different genera).
- Verater ater* Jordan, 1919a, p. 343 (new genus proposed).

Misidentifications: *Pteridium atrum* Emery, 1885, p. 158, fig. 21 (30 mm. specimen, description, probably *Benthocomeles robustus*).—Roule and Angel, 1930, p. 110, pl. 6, fig. 146 (Azores, description of postlarvae).

STUDY MATERIALS.—1 specimen, Nice, MCZ 26457.

COUNTS AND MEASUREMENTS.—(Measurements given in mm., followed by percent of standard length in parentheses) D 74; A 52; pectoral 19; vertebrae 40; caudal 10; vertical scale rows about 83; SL 89; body depth at dorsal origin 17.5 (19.7); predorsal 31.2 (35.0); preanal 50.0 (56.1); HL 25.0 (28.0); snout 5.8 (6.5); orbit 3.0 (3.4); upper jaw 14.2 (15.9); greatest maxillary width 4.5 (5.1); greatest head width 11.0 (12.3). (See D'Ancona, 1938, p. 162, for additional data.)

DESCRIPTION.—Squamation: Scales present on large area on top of head behind eye level; present on side of head on opercle and in area ahead of opercle extending forward nearly to eye and ventrally to region behind maxillary. Dorsal and lateral scale patches separated by scaleless lateral canal.

Lateralis system: Lateral canal with single pore near upper angle of opercle. Supraorbital canal with 2 pores: 1 in front of, and below, anterior nostril; the other, difficult to find, above anterior nostril. Infraorbital canal with 6 pores: 3 beneath nostrils in skinfold over upper jaw; 1 very small pore close to level of posterior part of eye; 2 larger pores above posterior expanded part of maxillary. Preoperculomandibular canal with 8 pores: 2 at tip of dentary, 1 opening anteriorly, the other posteriorly; 1 beneath lower lip at about midlength of snout; 1 at about midlength of jaw; 1 slightly ahead of posterior margin of maxillary; 1 slightly behind same; 2 on posterior margin of preopercle.

Circumorbital and interorbital areas and side of snout cavernous, covered with thick skin bearing scattered papillae. Interorbital area particularly rugose.

Lateral line marked by small, dark, dermal filaments. Series of 23 originates above opercle. Between opercle and level of dorsal fin origin filaments in elongate, irregular cluster from which lateral line extending posteriorly in straight line, between midline and dorsal profile. Dorsal line terminating 63 mm. from tip of snout. Second line of about 40 filaments originating in midline close to level of posterior tip of pectoral fin, descending, then rising to midline of body to form shallow irregular semicircle with lowest point opposite vent, then extending straight back in midline of body to tail. Filaments similar to those along lateral lines scattered about on head.

Dentition: Premaxillary with band of uniform granular teeth. Dentaries with similar teeth and irregular row of larger, conical teeth along inner edge of granular band. Head of vomer a broad

V with arms expanded. Both short granular and larger conical teeth present on vomer. According to Bellotti (1888), females of this species have the type of dentition noted above, although without larger teeth on the vomer, while males have both larger teeth and granular teeth on the premaxillary, vomer, and dentary.

Head spines: Short, sharp-pointed spine piercing skin at upper corner of opercle. Posteroventral margin of preopercle with 2 blunt projections at angles. Ventrally directed spine at end of maxillary prominent, piercing skin.

Vertebrae and ribs: Neural spines 5-13 short and broad but becoming progressively more elongate and narrower, their tips truncate neural spines on subsequent centra needle-like. Centra 7-11 with ribs at ends of parapophyses, subsequent centra lacking pleural ribs. Centra 4-8 with epipleurals attached to pleural ribs; on centra 9-13 epipleurals appear associated with parapophyses.

Color: Body light brown, vertical fins and head darker. Long in preservative, this specimen evidently was much darker in life. Risso used the common name "fanfre negre" and stated that the species was black.

DISTRIBUTION.—Known from the area around Nice, from Naples and from several localities in the Adriatic. Little is known of its depth distribution.

HABITAT.—Dwells in rocky areas in caves, according to Risso (1810), and apparently is secretive.

COMMENTS.—Professor D'Ancona (1938) has presented an excellent review of this species, and his paper should be consulted for information and references not given here.

Oligopus longhursti, new species

PLATE 3

STUDY MATERIAL.—All females. Holotype: USNM 187778, off Lagos, Nigeria in 5-10 fathoms, otter trawl, collected by A.R. Longhurst, August 1961. Paratypes: USNM 187779, 1 specimen, data as for holotype; USNM 191732, 2 specimens, Monrovia, Liberia, Bush Rod Island, beach seine, collected by George C. Miller, October 7, 1952; USNM 193678, 1 specimen, Liberia, 3-7 fathoms off mouth of St. Paul River, trawl, collected by George C. Miller, October 1, 1953.

COUNTS AND MEASUREMENTS.—See table 1.

DESCRIPTION.—Squamation: Scales present on large area on top of head behind eye level; present on side of head over opercle and area in front of dorsal half of opercle, which extends to within eye diameter of eye. Lateral scale patch bounded dorsally by scaleless

lateral canal and ventrally by scaleless area that demarcates separate patch of scales posterior to rear margin of maxillary.

Lateralis system: Lateral canal with 1 pore near upper angle of opercle. Supraorbital canal with 2 pores: 1 in front of anterior nostril; the other, very small, above anterior nostril. Infraorbital canal with 5 or 6 pores: 3 in row behind anterior nostril; 1, very small, near level of posterior margin of eye (absent in USNM 193678); and 2 above posterior expanded portion of maxillary. Preoperculo-mandibular canal with 8 pores: 2 at tip of dentary, 1 opening anteriorly, the other posteriorly; 1 beneath lower lip close to level of posterior nostril; 1 slightly ahead of level of posterior margin of maxillary; 1 near lower angle of same; 2 shaped like elongate slits, on posterior margin of preopercle.

Circumorbital and interorbital areas and side of snout cavernous and covered with thick skin bearing many small, dark, dermal papillae similar to those marking course of lateral lines along side of body. These filaments particularly abundant in interorbital region.

One series of lateral line filaments numbering about 35–45 and originating on head above opercle and, after slight irregular dip near origin, extending posteriorly in straight line between midline of dorsal profile, this dorsal line terminating more than half way back along body. Second line of about 35–40 filaments originating at about midline close to level of posterior tip of pectoral fin, descending, then rising to midline of body to form irregular semicircle having lowest point opposite origin of anal fin, then extending in straight line in midline of body to tail.

Dentition: Premaxillary bearing uniform band of granular teeth. Dentaries bearing similar teeth plus irregular row of larger, conical teeth along inner edge of granular band. Head of vomer with widely spread wings bearing short granular teeth. All four specimens females.

Head spines: Short, weak spine present at upper corner of opercle. May be buried beneath skin and invisible without dissection, or barely visible at its tip. Posteroventral margin of preopercle may be completely rounded or show 2 slight angles. Maxillary spine varying from prominent projection pictured in holotype to virtually absent condition in 1 Liberian paratype.

Vertebrae and ribs: Neural spines 5–13 short and broad but becoming progressively more elongate and narrower, their tips more or less (5 and 13) truncate; neural spines on subsequent centra needle-like. Centra 7–12 with ribs at ends of parapophyses, subsequent centra lacking pleural ribs. Centra 4–9 with epipleurals attached to pleural ribs; on centra 10–13 epipleurals appearing to be associated with parapophyses.

Color: Head and body brown, vertical fins black. Beneath superficial brown pigmentation of scales and scale pockets large, dark chromatophores distributed regularly on body.

DISTRIBUTION.—Known only from the type localities. Taken in beach seine and at 3–10 fathoms.

COMMENTS.—The holotype extruded fertilized eggs that must have been close to hatching and that are about 0.9 mm. in diameter. The Nigerian paratype has paired ovaries about 25 mm. long. Each contains an estimated 3,000 unfertilized eggs (based on counts and volumetric displacement on $\frac{1}{2}$ of 1 ovary), which are about 0.5 mm. in diameter. Eggs are of about the same size in all parts of the ovary; however, the eggs closest to the posterior end are more densely granular. One Liberian paratype (USNM 191732) extruded granular (unfertilized) eggs of about 0.5 mm. in diameter. The other Liberian specimen has its ovaries packed with an estimated several thousand young fish. The embryos are between 4 and 5 mm. long and have small yolk sacs and open choroid fissures. Elongate processes are attached to the embryo a short distance behind the yolk sac.

Oligopus robustus (Smith and Radcliffe)

Grammonus robustus Smith and Radcliffe in Radcliffe, 1913, p. 168, pl. 13, fig. 1 (original description, "Albatross" St. 5409, 10°38' N., 124°13' E.—Norman 1939, p. 79 (Gulf of Aden, 457–549 m.).—Kamohara, 1954, p. 5, fig. 3 (specimens from Kochi market, description).

Bythites lepidogenys (not Smith and Radcliffe, 1913) Kamohara, 1952, p. 93 (specimens from Mimase, description).

STUDY MATERIAL.—Holotype, USNM 74149, male.

COUNTS AND MEASUREMENTS.—(Measurements given in mm. followed by percent of standard length in parentheses) D 87; A 62; pectoral 25; vertebrae 46; caudal 8; vertical scale rows about 75; SL 129; body depth at D origin 32.5 (25.2); predorsal 42.2 (32.7); preanal 71.1 (55.1); HL 40.4 (31.3); snout 6.5 (5.0); orbit 6.5 (5.0); upper jaw 22.0 (17.1); greatest maxillary width 8.2 (6.4); greatest head width 21.2 (16.4). Additional meristic and morphometric data are presented by Kamohara (1954).

DESCRIPTION.—Squamation: Patch of scales present on nape. On sides of head, scales present on opercle and on area in front of opercle extending forward nearly to eye, dorsally to level of top of opercle, where scaleless lateral canal separates dorsal and lateral scale patches, and ventrally to area behind maxillary.

Lateralis system: Lateral canal with 1 pore near upper angle of opercle. Supraorbital canal with 2 pores: 1 below, and in front of anterior nostril tube; the other immediately above tube. Infraorbital canal with 6 pores: 3 beneath nostrils over upper lip; 1 at

level of posterior part of eye; 2 above posterior expanded portion of maxillary. Preoperculomandibular canal with 8 pores: 2 at tip of dentary, 1 opening anteriorly, the other posteriorly; 1 beneath lower lip near level of posterior nostril; 1 close to midlength of jaw; 1 ahead of posterior margin of maxillary; 1 behind same; 2 at posteroventral angle of preopercle.

Small, dark papillae scattered on head, concentrated in inter-orbital area. Lateral line marked by papillae similar to those on head. One series of 21 originating above opercle and, after slight irregular dip near origin, extending posteriorly in straight line between midline and dorsal profile, terminating at level of vent. Second line of about 25 filaments originating in midline at level of origin of anal fin and extending posteriorly in midline of body to point about 10 mm. from tail (the tail has become somewhat abraded and in all likelihood the lateral line actually continues to the base of the tail as shown by Radcliffe, 1913, and Kamohara, 1954.)

Dentition: Premaxillaries, dentaries, and broadly V-shaped vomer bearing bands of uniformly small, granular teeth.

Sex: Specimen male with prominent, paired testes about 20 mm. long.

Head spines: Small, sharp-pointed spine piercing skin at upper angle of opercle. Posteroventral angles of preopercle with 2 very blunt points. Maxillary spine prominent on right side of specimen, weakly developed on left side.

Vertebrae and ribs: Neural spines 5–15 short and broad, but becoming progressively more elongate and narrower; their tips truncate; neural spines on subsequent centra more needle-like. Centra 7–11 with ribs at ends of parapophyses, subsequent centra lacking pleural ribs. Centra 4–7 with epipleurals attached to pleural ribs; on centra 8–15 epipleurals appearing to be associated with parapophyses.

Color (in alcohol, quoted from original description): "Wood-brown; dorsal and anal dusky anteriorly, becoming dark clove brown posteriorly; the basal portion of caudal clove brown, distal portion somewhat lighter; pectorals dusky; peritoneum silvery gray."

DISTRIBUTION.—Known from Mimase, Japan; the Philippines between Cebu and Leyte, at a depth of 189 fathoms on a green mud bottom; and the Gulf of Aden between 25 and 30 fathoms.

***Oligopus waikiki*, new name**

PLATE 4

Microbrotula nigra Gosline, 1953, p. 220, fig. 1d (original description, off Waikiki Reef, Oahu, Hawaii).³

³ If *Microbrotula nigra* Gosline is referred to *Oligopus*, the specific name must be rejected as a junior secondary homonym of *Oligopus niger* Risso, which is a junior synonym of *Oligopus ater* Risso.

STUDY MATERIAL.—Holotype of *Microbrotula nigra*, USNM 179898, formerly UH 1684, female.

COUNTS AND MEASUREMENTS.—(Measurements given in mm., followed by percent of standard length in parentheses) D 98; A 71; pectoral 26; vertebrae 48; caudal 8; vertical scale rows about 72; SL 61.4; body depth at D origin 17 (27.7); predorsal 16.8 (27.4); preanal 30.0 (48.9); HL 15.9 (25.9); snout 3.2 (5.2); orbit 3.0 (4.8); upper jaw 9.0 (14.7); greatest maxillary width 3.6 (5.9); greatest head width 9.5 (15.5).

DESCRIPTION.—Squamation: Patch of scales present on nape. Second patch covers opercle and dorsal half of area in front of it, extending forward to within eye diameter of eye. Small, separate patch consisting of few scales present behind rear margin of maxillary.

Lateralis system: Lateral canal lacking pores. Supraorbital canal with 2 pores: 1 below, and in front of, anterior nostril tube; the other, very small, above tube. Infraorbital canal with 6 pores: 3 beneath nostrils over upper lip; 1 at level of posterior part of eye; 2 above posterior expanded portion of maxillary. Preoperculomandibular canal with 8 pores: 2 at tip of dentary, 1 opening anteriorly, the other posteriorly; 1 beneath lower lip near level of posterior nostril; 1 close to midlength of jaw; 1 slightly ahead of level of posterior margin of maxillary; and 3 shaped like elongate slits along posteroventral and posterior margin of preopercle.

Small, dark papillae scattered on muzzle and interorbital region. Lateral line marked by papillae. One series of about 20 originating above opercle and, after dip near origin, extending posteriorly to level of vent. Second line of about 35 papillae originating in midline at level of origin of anal fin and extending posteriorly in midline of body to tail, although posterior papillae very small.

Dentition: Premaxillaries and dentaries bearing bands of uniformly small, granular teeth. Vomer with 2 patches of similar teeth. Although Gosline (1953) noted the presence of palatine teeth, I find no trace of them.

Sex: Specimen female with small embryos in ovaries.

Head spines: Small, sharp-pointed spine piercing skin at upper angle of opercle. Posteroventral angles of preopercle bearing several weakly spinous points. Maxillary spine prominently developed.

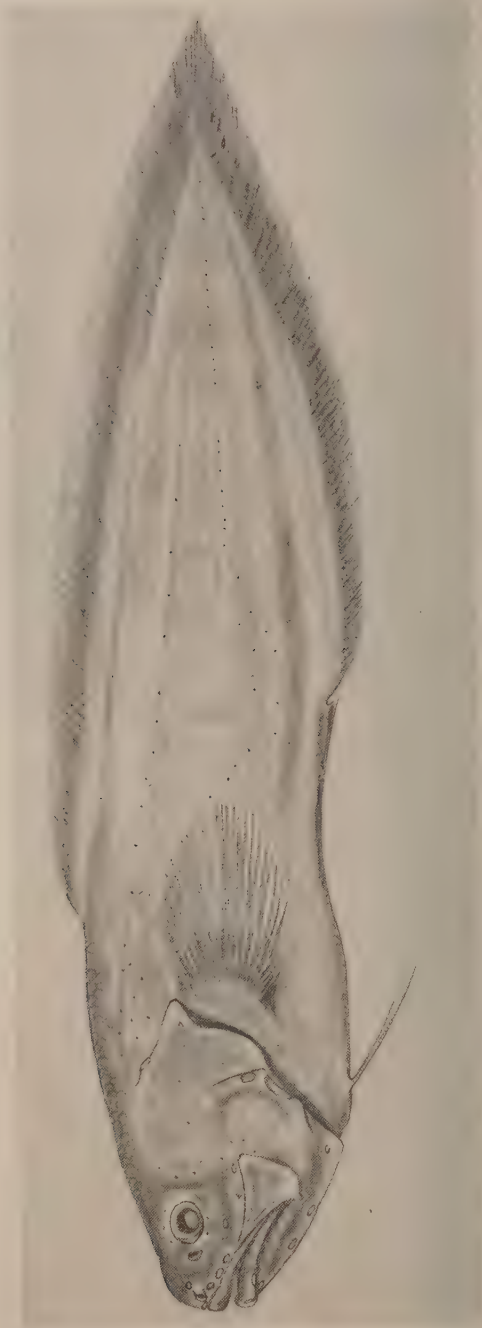
Vertebrae and ribs: Neural spines 5–14 short and broad, but becoming progressively more elongate and narrower, their tips truncate; neural spines on subsequent centra more needle-like. Centra 7–11 with ribs at ends of parapophyses, subsequent centra lacking pleural ribs. Centra 4–8 with epipleurals attached to pleural ribs; on centra 9–12 epipleurals appearing to be associated with parapophyses.

Color: Body brown, fins darker.

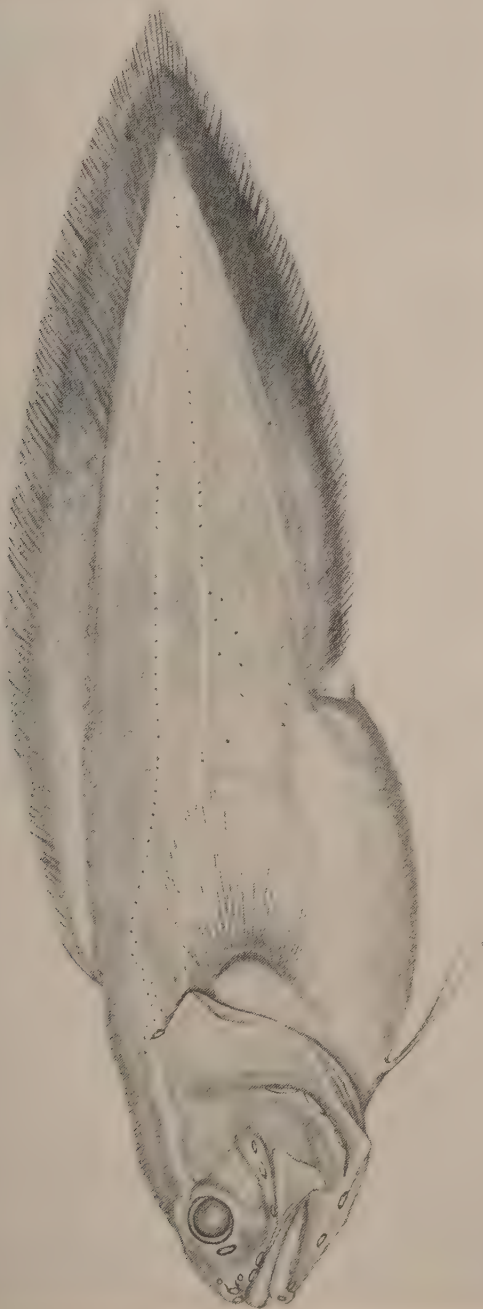
DISTRIBUTION.—Known only from the type locality at about 30 feet



X-ray photograph of *Oligopus diagrammus* (SIO H53-169, 185 mm. SL. Guadalupe Island, Mexico). Photograph by William L. Witt.

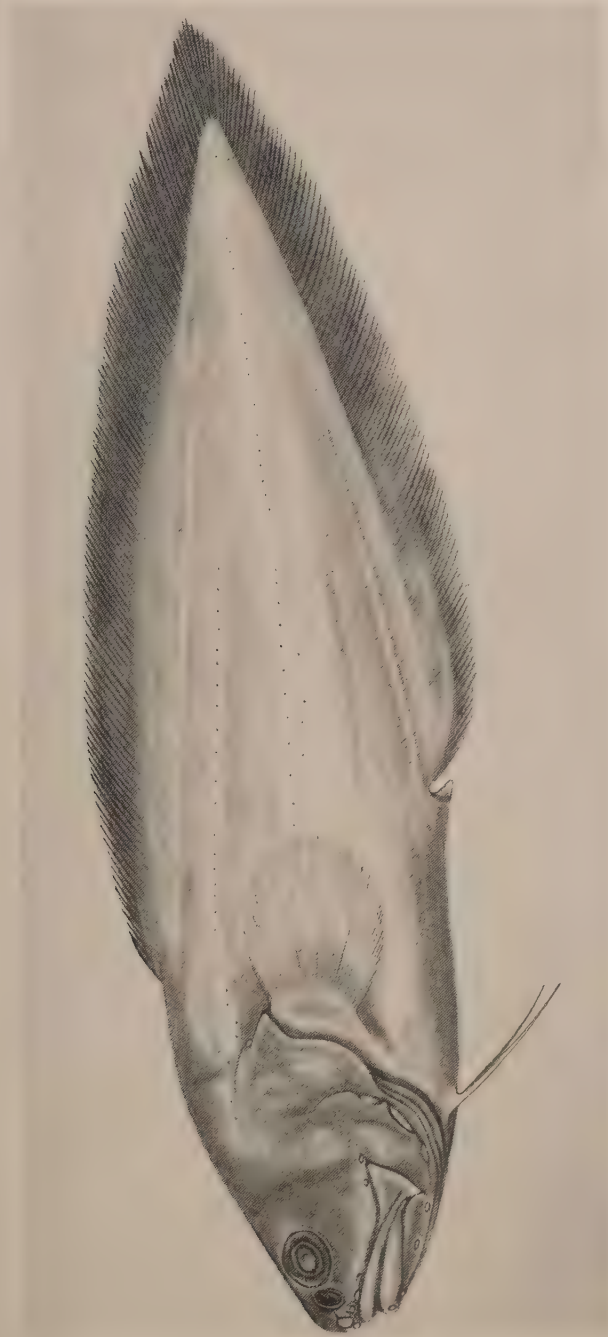


Oligopus ater (MCZ 26457. 89 mm. SL. Nice, France). Drawn by Mildred H. Carrington.



Oligoptus longhurstii (USNM 187778, holotype. 98 mm. SL. Lagos, Nigeria). Drawn by Mildred H. Carrington.





Oligopus diagrammus (SU 7059, paratype. 54 mm. SL. Galapagos). Drawn by Mildred H. Carrington.

Oligopus diagrammus (Heller and Snodgrass)

PLATES 1, 5

Eutyr diagrammus Heller and Snodgrass, 1903, p. 224, pl. 19 (original description, Galapagos, Tagus Cove, Albemarle Island, and Seymour Islands).—Böhlke, 1957, p. 3 (paratype of *E. diagrammus* compared with *Stygnobrotula latibricola*).

STUDY MATERIAL.—Holotype, SU 6346 and paratype SU 7059 from the Galapagos. The following from Guadalupe Island, Baja California, Mexico: SIO 58-497 (1); SIO 58-493 (1); SIO 54-213A (1); SIO 54-219 (1); SIO H53-169 (1); SIO 54-219A (6); SIO 60-14-61E (2). Following from peninsular Baja California or closely adjacent islands: SIO 61-272-61B, Espiritu Santo Island (3); SIO 61-227-61A, Cape San Lucas (2); SIO 61-242-61A (4); and SIO 61-249 (1), Los Frailes.

COUNTS AND MEASUREMENTS.—Caudal 10; vertical scale rows between 100 and 115, very difficult to count. Vertebrae 49–53. (See table 2 for a summary of measurements, and table 3 for counts.)

DESCRIPTION.—Squamation: Patch of scales on top of head posterior to interorbital. Patch of scales present on opercle and in front of opercle extending anteriorly to a point less than eye diameter behind eye. Dorsal and lateral scale patches appearing continuous in some specimens and separated by scaleless area over lateral canal in others (small size of scales and adherent mucous coating on head make this a difficult character of which to be certain). Scale patch posterior to hind margin of maxillary appearing to be continuously connected with main opercular scale patch.

Lateralis system: Lateral canal with 1 pore near upper angle of opercle. Supraorbital canal with 1 pore in front of, and below, anterior nostril. Infraorbital canal with 5 pores: 1 behind anterior nostril; 2 along lip below posterior nostril; and 2 above posterior expanded portion of maxillary. Preoperculomandibular canal with 8 pores: 2 at tip of dentary, 1 opening anteriorly, the other posteriorly; 1 beneath lower lip close to level of posterior nostril (not shown in fig. 4); 1 at about midlength of jaw (could not be found in holotype); 1 slightly ahead of posterior margin of maxillary; 1 slightly behind same. Two elongate slits along posterior margin of preopercle.

Circumorbital, interorbital, and opercular areas and snout bearing scattered papillae. Small dark papillae distributed on head but thickly dispersed in particular on top of head and over adjoining predorsal area of top of body.

Lateral line marked by small papillae. One series of about 30 originating on head above opercle and, after slight irregular dip behind opercle, extending posteriorly in straight line between midline

and dorsal profile. Dorsal line terminating slightly more than half way back along body. Second line of about 37-45 small papilla originating in midline close to level of posterior tip of pectoral fin not making pronounced dip at level of vent but extending straight back to tail with, at most, a slight irregularity near its origin.

Dentition: Dentaries with irregular row of sharply pointed teeth along inner margin of bone. Tooth-bearing area of bone broaden on anterior $\frac{1}{2}$ to $\frac{3}{8}$ of lower jaw. In specimens of less than about 100 mm., area exterior to large teeth occupied by granular teeth. In larger specimens these show gradual transition to second row of larger conical teeth that parallels inner row. Also 2 types of dentition on premaxillary. Specimens from 34 mm. to 81 mm. with uniform band of granular teeth, while those measuring 81 mm. and larger bearing row of large conical teeth along outer edge of band of granular teeth. Smaller specimens with only small granular teeth in broad V-shaped patch on head of vomer. Larger specimens with large conical teeth as well. Dentition in this species does not appear to be influenced by sex.

Sex: Two types of external sex organs, one consisting of stiff hood projecting posteriorly from vent and folding over genital area, the other consisting of only a low, fleshy ridge in place of prominent hood. In either type a delicate white papilla of varying length may be evident. Neither the two types of external genitalia nor the occurrence of the papilla appears to be correlated with sex as determined by gross observation of the gonads. In addition, at least one specimen (SI 61-272-61B, Espiritu Santo) and possibly others appear hermaphroditic. What I have interpreted as testicular tissue produces spermatozoa-like objects rather than free-running sperm suspension. If my observations are correct, then sex in this species is a complex problem that requires detailed study.

Head spines: Blunt, flat spine deeply buried in flesh of opercle in most specimens, but exposed in paratype. Ventrally directed maxillary spine prominent in most specimens.

Vertebrae and ribs: Neural spines 5-14 short and broad but becoming progressively more elongate and narrower, their tips truncate; neural spines on subsequent centra needle-like. Centra 7-11 with ribs at ends of parapophyses (although in some, ribs appear to articulate with centrum no. 7); subsequent centra lacking pleural ribs. Centra 4-9 with epipleurals attached to pleural ribs; 10, 13, 14, or 15 with epipleurals associated with parapophyses or haemal spines.

Color: Brown in preservative. In life: "Dark brown, head purplish-brown; fins blackish" (Heller and Snodgrass, 1903).

DISTRIBUTION.—Previously known only from the Galapagos to

about 3 fathoms. Here recorded from Guadalupe Island and Baja California.

COMMENTS.—The data on dorsal and anal fin ray counts presented in table 3 indicate that the Galapagos-Guadalupe populations and the Baja California populations of *O. diagrammus* have differentiated. Under ordinary circumstances I would recognize them as named taxa; however, it seems likely that additional populations will be discovered in the tropical eastern Pacific, and this, combined with the puzzling nature of sexuality in this species, makes me hesitant to do more than point out the differences and the problems involved in interpreting them.

Oligopus claudei (Torre)

Benthocometes claudei Torre y Huerta, 1930, opposite p. 171, unnumbered plate (original description, Cuba, Matanzas Bay); 1931?, p. 231, fig. (brief discussion).

Bathystorreuus claudei Howell Rivero, 1934, pp. 69–72, pl. 7 (new genus proposed, description).

Grammonus mowbrayi Grey, 1951, p. 154, fig. 1 (original description, type locality, Bermuda).—Collette, 1962, p. 443 (Bahamas).

STUDY MATERIAL.—The holotype of *B. claudei*, MCZ 33943 (in very poor condition). Three specimens ANSP Chaplin Bahama collections, St. 513; about $\frac{1}{4}$ mile N. of the center of Green Key, Bahamas; taken from inside a small, isolated coral head at a depth of 50 feet. One specimen, UP 1150; Puerto Rico, La Parquera, 6 miles offshore at vertical ledge, 65 feet. One specimen, UP 1151, Curaçao, cave at shore, about 100 meters SE. of entrance to bay.

COUNTS AND MEASUREMENTS.—See table 4.

DESCRIPTION.—Squamation: Scales present in patch over nape, on side of head over opercle and cheek, extending forward to a point less than eye diameter behind eye and ventrally to patch behind posterior margin of maxillary.

Lateralis system: Lateral canal with 4 pores in row: the most posterior above upper angle of opercle; the most anterior at junction of lateral canal and infraorbital canal. Supraorbital canal in Bahaman specimens with 4 pores extending in straight line from most anterior in front of anterior nostril to most posterior over rear half of eye; Puerto Rican specimen with only the 2 most anterior pores; and Curaçao specimen with the 3 most anterior pores on one side and the 2 most anterior pores on other side. Infraorbital canal with 8, 9, or 10 pores: 3 beneath nostrils; 1 smaller pore beneath eye about midway between orbit and lip; 2 or 3 pores in skin along maxillary sheath; and 2 or 3 pores in row extending up to lateral canal. Preoperculomandibular canal with 9–11 pores: 2 at tip of dentary, 1 opening anteriorly, the other posteriorly; 1 beneath lower lip at level of anterior margin of eye; row of 3

pores along medial edge of dentary, anteriormost about $\frac{1}{2}$ of distance along pore, posterior beneath end of maxillary: 1 small pore sometimes present lateral to middle pore of this series; 1 pore above angular; 2 on posterior margin of preopercle, and sometimes another above, and in front of, dorsalmost preopercular pore. The pore system is well illustrated in the figure given with the original description of this species (Torre y Huerta, 1930). One difference is that the Bahaman material lacks the pore on the posterior surface of the angular, as shown on the holotype.

Lateral line system along body variable and complex, consisting basically of 2 rows of papillae: one with about 35 papillae originating over opercle and extending posteriorly almost to tail in line between midline of fish and dorsal profile; the other, with about 25 papillae beginning slightly ahead of level of vent and, after an irregular beginning, proceeding posteriorly almost to tail in straight line between midline of fish and ventral profile of fish. In addition to these basic lines (illustrated on the figure of the holotype), there are a profusion of other papillae whose distribution will not be described in detail. Suffice it to say that some are distributed virtually at random, some are in short series above or below the main lines, some are in short rows in the midline of the fish.

Papillae also scattered about on head, as are very small dermal filaments; however, no rugose areas on head.

Dentition and sex: In two specimens a band of granular teeth on premaxillary, another on dentary. Head of vomer carrying 2 large bony knobs, each with patch of granular teeth, each patch connected by narrow line of short teeth. Three other specimens with band of granular teeth noted above and, in addition, with irregular single row of larger conical teeth located lateral to granular row on premaxillaries and medial to granular row on dentaries. A few vomerine teeth also slightly enlarged. Specimens with granular teeth with only a small, fleshy flap over genital area. Other 3 with prominent, stiffened hoods; at least 1, UP 1151, with well-developed testes.

Head spines: Short, sharp spine piercing skin at upper angle of opercle. One specimen with several short spines at lower angle of opercle. Two short, sharp spines at lower angle of preopercle. Ventrally projecting premaxillary spine prominent, angular projecting downward as prominent blunt spine.

Vertebrae and ribs: Neural spines 5-13 or 14 short and broad but becoming progressively more elongate and narrower; their tips truncate. Neural spines on subsequent centra needle-like. Centra 7 with free ribs, although rudiments of parapophysis visible on X-ray photograph of 1 specimen. Centra 8, 9, and 10-12 with ribs at ends of parapophyses, subsequent centra lacking pleural ribs. Centra

-8 with epipleurals attached to pleural ribs; on centra 9-13 or 14, pipleurals associated with parapophyses or haemal spines.

Color: Body light brown; vertical fins dark, particularly on their vertical margins.

DISTRIBUTION.—Bermuda, the Bahamas, Puerto Rico, and Curaçao.

COMMENTS.—The holotype of *O. claudei* is in such poor condition that accurate measurements are impossible, and observations on the lateral system are subject to question. It does seem certain, however, that, with the material at hand, there is no way of maintaining *Trammonus mowbrayi* Grey as a valid species.

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TABLE 1.—*Counts and measurements of Oligopus longhursti*

Counts	Holotype USNM 187778	Paratype USNM 187779	Paratype USNM 191732	Paratype USNM 191732	Paratype USNM 193678
Dorsal	88	89	83	85	86
Anal	58	61	58	61	59
Pectoral	25	24	25	25	25
Vertebrae	45	44	45	45	44
Caudal	8	8	8	8	8
Vertical scale rows (approximately)	120	—	120	120	120
Measurements	mm. %SL	mm. %SL	mm. %SL	mm. %SL	mm. %SL
Standard length	98.0 —	92.6 —	105 —	105 —	106 —
Body depth at dorsal origin	27.0 27.5	23.5 25.4	25.0 23.8	— —	— —
Predorsal	30.0 30.6	29.5 31.9	31.4 29.9	32.5 30.7	33.5 31.6
Prealal	50.5 51.5	48.5 52.4	55.1 52.5	53.0 54.7	60.4 56.9
Head length	25.6 26.1	24.3 26.2	26.2 24.9	26.9 25.4	28.5 26.7
Snout	5.9 6.0	5.7 6.2	6.2 5.9	5.2 4.5	6.2 5.8
Orbit	4.5 4.6	3.5 3.8	3.5 3.3	4.2 4.0	4.0 3.8
Upper jaw	15.0 15.3	14.0 15.1	14.8 14.1	14.5 13.7	15.5 14.6
Greatest width of maxillary	5.4 5.5	5.0 5.4	4.7 4.5	4.2 4.0	4.2 4.0
Greatest width of head	15.0 15.3	13.0 14.0	16.0 15.2	16.1 15.2	— —

TABLE 2.—*Summary of measurements on O. diagrammus from three geographical localities (given as percent of standard length; average in parenthesis followed by range)*

Measurement	Galapagos-N=2 ¹	Guadalupe-N=13	Peninsular Baja Calif.-N=8
Range in standard length (mm.)	91.54	74.7-184	34.5-81.0
Depth at dorsal origin	23.6 (21.4, 25.9)	24.5 * (21.3-32.1)	23.1 (20.9-25.2)
Predorsal	29.5 (28.6, 30.4)	29.1 (26.3-30.9)	29.4 (26.3-31.9)
Prealal	44.1 (43.9, 44.4)	47.3 (46.3-51.3)	46.3 (43.8-48.1)
Head length	26.6 (25.5, 27.8)	26.0 (25.1-27.2)	26.9 (25.3-27.8)
Snout	5.9 (5.4, 6.5)	5.2 (4.6-6.2)	5.7 (4.9-6.6)
Orbit	5.0 (4.4, 5.6)	4.3 (3.8-4.7)	4.8 (4.7-6.1)
Upper jaw	13.8 (14.7, 13.0)	13.2 (12.5-13.8)	13.7 (12.8-14.4)
Maxillary width	4.35 (4.3, 4.4)	4.4 (3.9-4.7)	4.5 * (4.0-5.0)
Head width	14.9 (13.4, 16.5)	14.2 (12.0-17.7)	13.3 (11.1-17.3)

¹ First number in parenthesis is holotype, second is paratype.² N=12.³ N=5.

TABLE 3.—Meristic data for *O. diagrammus* from three geographical localities

[illegible]

TABLE 4.—*Counts and measurements of Oligopus claudel*

Counts	Holotype MCZ 33943		3 specimens from Chaplin Bahama coll. sta. 513				Puerto Rico UP 1150		Curaçao UP 1151	
	mm.	%SL	mm.	%SL	mm.	%SL	mm.	%SL	mm.	%SL
Dorsal fin rays	88		87		86		85		82	
Anal fin rays	162		66		67		69		64	
Pectoral fin rays	25		24		24		25		23	
Vertebrae	43		43		43		43		41	
Caudal fin rays	-		10		10		10		10	
Vertical scale rows (approx.)	75+		80		79		-		75	
Measurements										
Standard length	90	(approx.)	79.1		80.6		80.6		58.4	
Body depth at dorsal origin	-		-		22.2		23.0		15.6	
Predorsal	-		29.1	36.8	28.7		27.4		19.5	26.7
Prenasal	-		41.2	52.1	41.8		41.0		32.2	33.4
Head length	-		23.2	29.3	25.3		25.1		20.7	27.9
Snout	-		5.2	6.6	6.2		6.3		3.1	28.9
Orbit	-		3.6	4.6	4.0		3.8		3.9	6.7
Upper jaw	-		13.0	16.4	13.4		14.0		2.7	4.4
Greatest width at maxillary	-		5.0	6.3	5.2		5.4		2.6	6.9
Greatest width of head	-		15.0	19.0	15.1		15.4		9.9	16.9
							7.6		4.0	8.7
							16.9		14.9	

1 Possibly several more.

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Bioluminescence in the Gulf of Mexico Anacanthine Fish
Steindachneria argentea

DANIEL M. COHEN

Bioluminescence in the Gulf of Mexico Anacanthine Fish *Steindachneria argentea*

DANIEL M. COHEN

Both living and dead specimens of the Gulf of Mexico anacanthine fish *Steindachneria argentea* were injected with a 1:1,000 solution of adrenalin chloride. In some instances luminescence was induced. The skin of areas observed to luminesce has a distinctive, striated pattern of pigment distribution. Similar skin has been reported from the macro-urid genus *Hymenocephalus* and 3 species of the family Trachichthyidae, of which one, *Paratrachichthys prosthemi*, is known to be luminescent. A luminous organ is present in the body wall where it forms a ring around the anus which is located anteriorly between the bases of the ventral fins. An elongate cavity filled with gelatinous tissue extends posteriorly from the anus to the origin of the anal fin. Gelatinous tissue is also found beneath virtually all striated skin. The ventral part of the hypaxial muscle mass is modified into a structure to reflect and diffuse light.

THE anacanthine fish *Steindachneria argentea* is a common inhabitant of the continental shelf in the Gulf of Mexico. Observations were made of adrenalin-induced bioluminescence in this species during cruise number 82 of the Bureau of Commercial Fisheries exploratory fishing vessel OREGON. Although luminescence has been long recognized in anacanthine fishes (see Haneda 1951 for examples and references), the photogenic organs of *Steindachneria* appear unique within the order.

Bottom trawling was conducted near the Mississippi Delta between 22 October and 3 November 1962. Specimens of *Steindachneria* were taken between 100 and 200 fathoms. The procedure was to select several specimens immediately after the trawl was emptied on deck. Specimens were then placed in chilled seawater (bottom temperatures at about 200 fathoms in the area were 10 to 11 C while surface temperatures ranged from about 18 to 22 C) and carried to a dark cabin where they were injected with a 1:1,000 solution of adrenalin chloride (Parke Davis and Co.). A 1-cc tuberculin syringe was used.

Station 4001, 100 fathoms, fishing time 0150-0345 hr. A living specimen was injected intramuscularly on the belly with 0.65 cc of adrenalin chloride solution. Some solution may have dispersed beyond the belly muscles. A faint bluish glow started around the anus and extended posteriorly,

forming a luminous streak between the vent and the genital opening (see Parr 1946 Fig. 1). Within a few minutes the side of the head and the entire ventral fifth of the fish emitted light. After about a minute the glow subsided and the fish was returned to chilled seawater. Stroking the venter of the fish caused a renewal of the luminescence, and also caused some luminescent material to rub off on my fingers. A living specimen not injected with adrenalin showed only a very small amount of luminescence when stroked. The area around the vent of the injected specimen was still glowing when the fish was preserved, 1 minute after the initial injection.

Station 4002, 150 fathoms, fishing time 0410-0635 hr. A dead specimen was injected intermuscularly on the belly with about 0.50 cc. A faint temporary glow appeared near the vent.

Dead specimens from the following stations gave no response: 4028, 195-200 fathoms, day haul, 2, 0.5 cc each; 4029, 19 fathoms, day haul, 2, 0.6 cc each; 4030, 185-190 fathoms, night haul, 1, 0.5 cc; 4031, 200-205 fathoms, night haul, 1, 0.5 cc; 4032, 185-190 fathoms, day haul, 1, 0.5 cc.

Station 4035, 190-195 fathoms, day haul. Two dead specimens injected with 0.6 cc each. One fish lighted up very suddenly and brightly along the ventral surfaces of the body and the mandibles. The light did not diffuse along the body as in 4001, but



Fig. 1. Ventral view of the belly of *Steindachneria argentea* showing the urogenital opening anterior to the base of the anal fin, and the luminous streak, outlined in dark pigment, between the two. $\times 2$.

med to appear instantaneously in all illuminated areas. It lasted only a few seconds and could not be reinduced, either chemically or mechanically.

Station 4036, 190–195 fathoms. Two newly living specimens injected with 0.6 cc each showed a faint glow ventrally.

Observations of luminescence in specimens collected during both day and night indicate that there was no diurnal inhibition of adrenalin-induced luminescence. Whether diurnal inhibition is present naturally is not known.

Parr (1946), in writing of *Steindachneria*, noted the remarkable separation between the vent, which lies between the ventral fins, and the genital opening, which is located immediately in front of the anal fin (Fig. 1). The luminescent apparatus is intimately associated with these two structures. A doughnut-shaped organ lies in the body wall, outside the peritoneal cavity, and completely surrounds the distal portion of the anus (Fig. 2). Kuwabara (1955) described a similar situation in *Paratrachichthys prosmius*. This organ is composed of folded nodular tissue enclosed within a thick membrane which is black on the dorsal face of the organ and silvery elsewhere. The body wall along a midsagittal section between the anus and the genital area (the portion of the luminous streak mentioned under Station 4001) lacks muscular tissue.

Instead, a transparent, gelatinous material is present. In one specimen, initially preserved in 75% ethyl alcohol, this region is an elongate empty cavity. At the level of the genital opening, the gelatinous tissue divides and continues posteriorly on each side of the anal fin, forming a layer between the skin and the underlying translucent ventral muscle mass. Gross dissection has not revealed any duct from the luminous doughnut to the luminous streak.

As for the remainder of the body and the head, the pigment pattern indicates which areas were observed to luminesce (Fig. 3). In fresh specimens, the side of the body is divided into three sections of unequal width. The upper two-fifths of the body is iridescent; the middle two-fifths is a flat, silvery color flecked with dark pigment. The lower fifth of the body is silvery blue and is distinguished by countless parallel dark lines (Fig. 4) which converge toward the midventral line of the trunk and tail and give this region a striated appearance (Parr 1946:6 also noted this peculiar pattern). The same type of skin is also present around the base of the pectoral fin, on the side of the head behind the eye, on the isthmus, and on the bottom of the head. When the fish is viewed ventrally, the striated skin is the only kind visible. The distribution of the striated pigment pattern coincides with the observed areas of luminescence. An apparently identical striated pattern of skin pigmentation has been observed in species of the macrourid genus *Hymenocephalus* (Gilbert and Hubbs 1916: 186 noted the similarity to this tissue in *Steindachneria*), and the trachichthyid fishes *Hoplostethus metallicus* (Fowler 1938: 38 suggested that this tissue might be luminous), *Paratrachichthys prosmius* (Hanedá 1957 observed that areas covered with

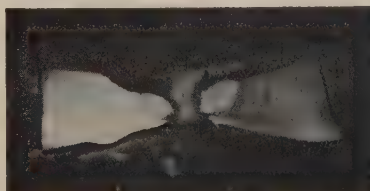


Fig. 2. Midsagittal section through ventral body wall at region of anus in *Steindachneria argentea*. Anterior of fish to the left. Anus in the center, encircled by the luminous organ. $\times 2.2$.

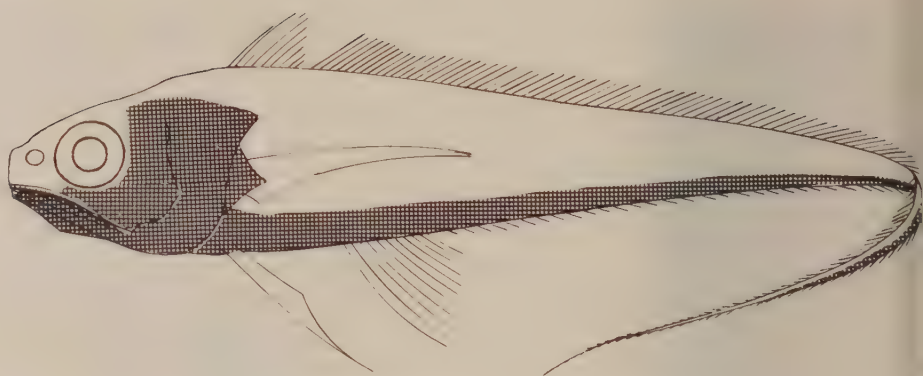


Fig. 3. Diagram of *Steindachneria argentea* with area observed to luminesce darkened. Drawn by Mildred H. Carrington.

striated skin luminesced when stimulated), and *Paratrachichthys argyrophanus* (Woods 1961).

Haneda (1957) suggested that pigment covering the luminous areas may screen light in some way.

A cross section through the tail (Fig. 5) shows the ventralmost part of the hypaxial muscle mass distinguished from the other trunk and tail muscles by a more dense texture and whiter color in specimens preserved in 75% ethyl alcohol and Bouin's fluid. The septum separating the ventral muscle mass from the dorsal muscles is silvery white ventrally and bears large dark chromatophores dorsally. These distinctions are not as easily observable in formalde-

hyde-fixed specimens. Unfortunately, no observations were made on fresh material. It seems likely, however, that in life the septum is a reflector and the ventral muscle mass is translucent and acts as a diffuser of light. The ventral muscle mass of *Steindachneria* resembles the filiform body (the postanal luminous area) of *Paratrachichthys prothemius* as described by Haneda (1957). He stated, "This muscle tissue is cloudy translucent . . . and diffused light will pass through it easily to the end of muscle tissues."



Fig. 4. Striated skin taken from luminescent area at base of pectoral fin of *Steindachneria argentea*. $\times 7$.

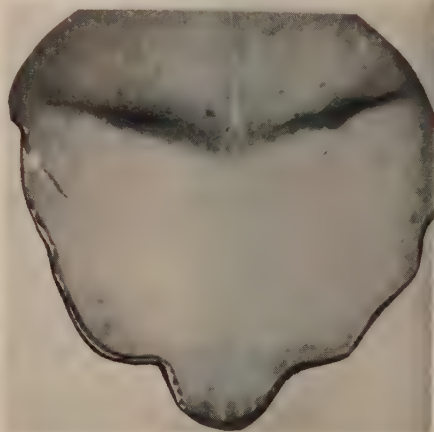


Fig. 5. Cross section of ventral muscle mass from tail of *Steindachneria argentea*. Section taken 37 mm behind the origin of the anal fin on a fish which is 230 mm in standard length. $\times 10$.

It seems likely, because of its resemblance to *Paratrachichthys prothemius*, that the luminescence of *Steindachneria* is caused by bacteria which reproduce within the luminous organ. Secretions possibly travel posteriorly to the genital area along the duct filled with gelatinous tissue dorsal to the externally visible luminous streak (Fig. 1). Similar gelatinous tissue beneath virtually all striated skin is possibly also a pathway for diffusion. If, however, the organ around the anus is the only source of luminescence, it remains to be seen how photogenic secretions can reach the areas of the head which have been observed to luminesce. Another alternative which deserves consideration is that the heavily pigmented dark lines which exteriorly delimit the luminescent area play an active role in light production. Dr. Stanley Weitzman (personal communication) has suggested another hypothesis, the possibility that the nervous system may play a role in stimulating luminescence in bacteria present in the gelatinous tissue beneath the striated skin. This explanation would help account for the sudden bright flash described under Station 4035.

I am indebted to Mr. Harvey R. Bullis and to the other scientists and the crew on board the OREGON for their cooperation in making these observations possible. Mr. Loren P. Woods, Mrs. Marion Grey, and

Dr. Stanley Weitzman have given helpful comments.

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PROCEEDINGS
OF THE
BIOLOGICAL SOCIETY OF WASHINGTON

LYCENCHELYS BULLISI, A NEW EELPOUT FROM
THE GULF OF MEXICO

BY DANIEL M. COHEN

U. S. Fish and Wildlife Service, Washington, D. C.

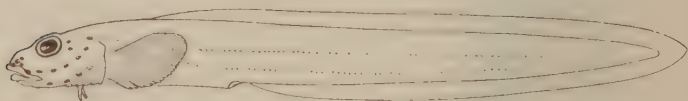
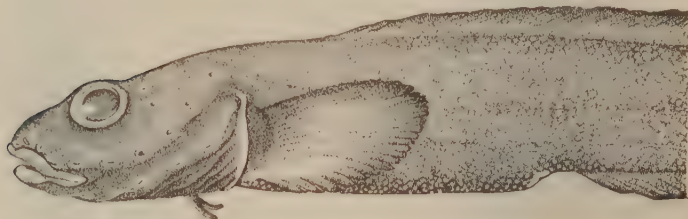
The two specimens of eelpout described in this paper were captured by the Bureau of Commercial Fisheries vessels "Oregon" and "Silver Bay" during exploratory fishing investigations in the Gulf of Mexico. They represent, to the best of my knowledge, the only known occurrences of the family Zoarcidae (excepting the bathypelagic genus *Melanostigma*) in the Gulf of Mexico. It is not possible to identify these fishes with any known eelpout, and I therefore consider them to represent a species new to science. The nomenclature of the head pores follows Andriashev (1955). Vertical fin ray elements and vertebrae were counted from an X-ray photograph. Illustrations are by Mildred H. Carrington. I am indebted to Dr. C. Richard Robins of the University of Miami and to Dr. Giles W. Mead of Harvard University for allowing me to examine material in their care.

***Lycenchelys bullisi*, new species**

Holotype: U. S. National Museum no. 188232, "Oregon" station 4038, 28°51' N, 88°41' W, 400-410 fathoms (732-750 m); 3 Nov. 1962; 40-foot flat trawl; off the mouth of the Mississippi River. Although no bottom temperature was taken at station 4038, the bottom temperature at 300 fathoms (549 m) at nearby station 4005, 29°07.5' N, 88°09' W, was 8.5°C.

Paratype: University of Miami Marine Laboratory no. 5363, "Silver Bay" station 1195, 24°26' N, 83°33' W, 350 fathoms (640 m); 8 June 1959; 40-foot flat trawl; west of Key West.

Diagnosis: A *Lycenchelys* with a relatively short body, depth behind vent into total length 11.2 to 12.2 times; a short head, 6.6 to 6.8 in total length; a large eye, 3.6 to 3.9 in head; a relatively great preanal distance, 2.8 in total length; two lateral lines; plain, unpatterned coloration.

FIG. 1. Holotype of *Lycenchelys bullisi*. Outline drawing.FIG. 2. Holotype of *Lycenchelys bullisi*.

Counts and measurements: Measurements in millimeters; holotype first, followed by paratype in parentheses. Dorsal fin rays 100 (100); anal fin rays 83 (83); caudal fin rays (including only those rays which articulate with the hypural) 11(10); pectoral fin rays 18 (17); ventral fin rays 1 (1); vertebrae (not including hypural) 24 (24) abdominal + 81 (79) caudal = 105 (103); total length 180 (173); standard length 174 (167); snout to anal fin 64 (62); head length 27.1 (25.5); snout length 6.6 (7.0); horizontal diameter of eye 7.5 (6.6); postorbital length of head 13.0 (12.4); tip of snout to origin of ventral fins 21.4 (20.5); length of pectoral fin 19.0 (18.5); depth of body behind level of vent 16.0 (14.2); depth of body at ventral fin 14.0 (14.5); interorbital width 5.6 (5.4); gill opening 8.6 (9.0).

Description: Body relatively short for a *Lycenchelys*, compressed. Greatest depth of body in the trunk region anterior to the vent, decreasing in depth only very gradually along the tail. Width of trunk at level of vent about one-half depth; body more compressed posteriorly. No keel-like ventral fold on the abdomen.

Unpaired fins confluent, their height nearly uniform. Origin of dorsal fin on vertical through midlength of the pectoral fin; length of pectoral fin equal to about one-half the distance from origin of pectoral fin to origin of anal fin. Pectoral fin inserted vertically immediately behind opercle. Each ventral fin ray 3 to 4 mm long.

Scales absent from head, predorsal area of dorsum, and from side of body above proximal one-fourth of pectoral fin. Remainder of body with scales, as are the bases of the vertical fins. Thirty to 35 scales between vent and base of dorsal fin (only 24 shown in Fig. 2). Lateral line originating at the occipital pore, whence it extends posteriorly in a straight line for about 10 mm, then descends to the lower third of the

body and extends posteriorly to almost the end of the tail; very difficult to trace beyond the vent. Another lateral line originates in the midline close to the level of the hind margin of the pectoral fin and extends straight back for a distance of 65 to 70 mm, becoming indistinct posteriorly (virtually impossible to see in the paratype).

Head width about equal to head depth, both at nape and at interorbital. The dorsal profile of the head descends gently from the nape and is interrupted by the dorsal rim of the eye in the holotype, not in the paratype. In the holotype an inflection occurs near the level of the tubular anterior nostril, whence the profile descends more steeply. The snout of the paratype is smoothly rounded. Snout short, about equal in length to horizontal diameter of eye. The nostril tube is closer to the tip of the snout than to the anterior rim of the eye and is located a distance about equal to its own diameter above the upper lip. The posterior nostril resembles the sensory pores and is located above and behind the nostril tube.

Seven pores in the maxillary series, the first in front of the anterior nostril; two postorbital pores, both behind the eye; a single occipital pore, near the upper angle of the opercle; a single preopercular pore, about midway between the hind margin of the eye and the hind margin of the opercle; mandibular series with seven pores, the anterior four, which are located along the lower jaw, separated by prominent folds of skin in the holotype.

Posterior margin of maxillary not reaching beyond level of midpoint of eye. Eye large, 3.6 to 3.9 in head. Interorbital region slightly concave in holotype, flat in paratype. Mouth slightly inferior, loose skin on upper lip protruding only slightly, not expanded into fleshy flap.

A slight palatal membrane present. Teeth short and conical; on the dentary in a single row which expands into a patch near the symphysis. Each premaxillary with 6 to 12 teeth in a single row, a second row of 4 teeth at the symphysis in the holotype. Four or five teeth on the vomer, separated by a short gap from 4 teeth in a row on the palatine.

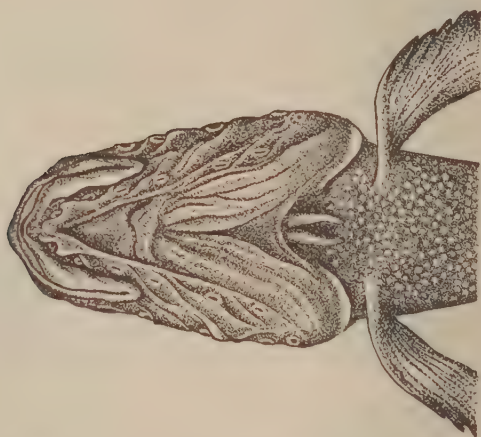
Last abdominal centrum lacking pleural ribs on its parapophyses.

Body color of the holotype a uniform light brown; the darkly pigmented peritoneum shows through the trunk region; the fins are dark. The paratype is faded and was probably dead when preserved.

The holotype is a ripe female containing about 10 large granular unfertilized eggs. One egg measured 3.5 by 4.5 mm. The paratype is probably a male.

Relationships: With the exception of its less elongate body and fewer vertebrae, *L. bullisi* fits fairly well the tentative definition of *Lycenchelys* proposed by Andriashev (1955). Although use of relative body length would place *L. bullisi* in *Lycodes*, the presence of prominent head pores and a palatal membrane are more important characters and are better reasons for relating the species to *Lycenchelys*.

L. bullisi is separable from any known *Lycenchelys* on the basis of its relatively short head, snout and body. It seems to have its closest rela-

FIG. 3. Holotype of *Lycenchelys bullisi*. Ventral view of head.

tionships with a group of plain-colored species which previous authors have described in *Lycodes* (where they would be relatively elongate forms); these are *L. microcephalus* Jensen (1904) from 1461 meters southwest of Iceland; *L. atratus* Vladykov and Tremblay (1936) from 150 meters in the estuary of the St. Lawrence River, and *L. incisus* Garman (1899) from 1261 meters in the Gulf of Panama. *L. bullisi* is separable from all three of these species on the basis of counts and

TABLE 1.—Counts and measurements expressed as percent of total length in the types of four species of eelpout

	<i>L. bullisi</i>		<i>L. micro-</i> <i>cephalus</i>	<i>L.</i> <i>atratus</i>	<i>L.</i> <i>incisus</i>
	Holotype	Paratype			
Total length (mm)	180	173	81	255	196*
Sex	♀	♂?	immature	♀	♀
Dorsal rays	100	100	87	112	101
Anal rays	83	83	71	93	84
Pectoral rays	18	17	15	22	18
Vertebrae	105	103	—	116	—
Preanal distance	35.5	35.8	38.3	41.2	36.0
Head length	15.1	14.7	17.3	22.2	20.6
Snout	3.7	4.0	—	—	5.9
Eye diameter	4.2	3.8	—	4.3	2.2
Body depth at vent	8.9	8.5	8.0	10.2	8.0

* The smaller of two syntypes. The larger is broken behind the vent.

proportions. Comparisons are presented in Table 1. The data for *L. microcephalus* and *L. atratus* are from descriptions of these species. The data for *L. incisus* were taken from one of the syntypes.

Nomenclature: Named for Harvey R. Bullis in recognition of his contributions to knowledge of the marine fauna of the tropical western Atlantic.

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A REVIEW OF THE OPHIDIROID FISH GENUS *LUCIOBROTULA* WITH THE DESCRIPTION OF A NEW SPECIES FROM THE WESTERN NORTH ATLANTIC

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ABSTRACT

Luciobrotula has heretofore been known from the Philippines, Japan and the Gulf of Aden. The genus is redefined and *Volcanus*, from Hawaii, is relegated to the synonymy of *Luciobrotula*. A new species from the Gulf of Mexico, Caribbean, and tropical western Atlantic is described.

INTRODUCTION

The species described as new in this paper was trawled by the Bureau of Commercial Fisheries exploratory fishing vessel OREGON. I am much indebted to Harvey R. Bullis, Jr., for placing specimens at my disposal. While studying the western Atlantic material reported upon herein it became apparent that it was most closely related to the recently described Hawaiian genus *Volcanus* Gosline, 1954. Further study revealed that *Volcanus* and *Luciobrotula* Smith & Radcliffe, 1913, are congeneric and this genus is diagnosed and considered to contain three species.

All of the previously unreported specimens described in this paper are distorted. They share in common with the holotype of *Volcanus lineatus* the fact that their heads are thrown back and their branchial membranes and opercles are flared out. For this reason, measurements are not as precise as might be desired. Counts of rays in the dorsal, caudal and anal fins, and numbers of vertebrae were taken from X-ray photographs. Definitions of most of the counts and measurements are given in Cohen (in press). One additional measurement is *preventral*, distance from the tip of the lower jaw to the base of the ventral fin.

I am indebted to Bruce B. Collette of the Bureau of Commercial Fisheries, Walter R. Courtenay, Jr., of Duke University and William A. Gosline of the University of Hawaii for their kindness in reviewing the manuscript.

Genus *Luciobrotula* Smith & Radcliffe, 1913

Luciobrotula Smith & Radcliffe, 1913, in Radcliffe, 1913, p. 170 (type species by original designation, *Luciobrotula bartschi* Smith & Radcliffe).

Volcanus Gosline, 1954, p. 78 (type species by original designation, *Volcanus lineatus* Gosline).

External intromittent organs absent, species probably oviparous. Body elongate, but the tail not greatly elongated and tapering. Barbels absent;

shaft of maxillary sheathed beneath the eye; however, posterior margin of maxillary greatly expanded and free. Small, granular teeth present on premaxillaries, dentaries, vomer and palatines; gill rakers three; tongue small, with a sharp anterior extension. Branchiostegal rays eight; a weak spine buried in the flesh near the upper angle of the opercle; posterior margin of preopercle free, lacking spines. Body completely covered with small cycloid scales, as are the bases of the pectoral and vertical fins; snout naked, bearing a series of fleshy flaps and ridges, pores and pit organs; a single, incomplete lateral line tube extending along the side of the body over the scales and dorsal to the midline. Tubular anterior nostril about midway between posterior nostril and tip of snout, not on upper lip. Eye small, with horizontal diameter greater than vertical.

Vertical fins confluent but caudal fin exserted. Each ventral fin with two rays; ventral fin originating behind the symphysis of the cleithra by a distance equal to at least the vertical diameter of the eye and at or behind the level of the posterior margin of the preopercle. The two ventral fins closely adjacent, not separated by an interspace. Pectoral fin broadly rounded, supported on a fan-like, fleshy, scale-covered base, lacking any free or elongated rays.

Neural spine on first centrum shorter than subsequent spines; neural spines on abdominal vertebrae depressed, the posterior ones with more or less truncate tips. Ribs present on first two centra. Anterior ribs serving as swimbladder support. First three ribs with thickened leading edges and thin, blade-like posterior expansions.

Pyloric caecae absent. Lining of body cavity dark; lining of mouth and branchial cavity pale.

Discussion—Gosline (1954) related *Volcanus* to *Luciobrotula*. I have examined the holotype and one other, previously unreported specimen of *L. bartschi*, the single species described in the genus, and I can find no generic differences distinguishing *Volcanus* from *Luciobrotula*. Gosline stated that *Volcanus* differed from *Luciobrotula* in lacking a lower opercular spine; in having an incomplete, tubular lateral line; in having flaps and lines (*i.e.*, ridges) on the snout and in having scales on the upper part of the suborbital area and on the area between the posterior nostrils and the eye. I will discuss each of these characters.

1. Opercular spine. Virtually all ophidioids have an inverted, L-shaped process on the opercle. It is skin-covered with only the postero-dorsal point, which is the so-called opercular spine, protruding in most species. The holotype of *L. bartschi* was apparently initially preserved in alcohol causing the skin to shrink against the body. In addition, the skin has partially cleared so that the end of the ventral arm of the inverted L-shaped opercular process is visible. This is the "lower spine" mentioned

by Smith & Radcliffe (*in* Radcliffe, 1913) in their original description of *L. bartschi*. *Volcanus* possesses an identical structure beneath the skin of the opercle. One difference between the two nominal genera, however, is that in *Volcanus* the tip of the upper opercular spine is rather flattened in cross section, and blunt, while in *Luciobrotula* the spine is round in cross section and sharp.

2. Lateral line. Interpretation of this character was also affected by poor preservation. Careful observation of the holotype of *L. bartschi* leads me to believe that the lateral line in *Luciobrotula* is similar to that in *Volcanus*. I find no trace of the posterior section of the lateral line illustrated by Radcliffe (1913). There are, however, some darkly pigmented remnants of what appears to have been a lateral line tube running parallel to the dorsal profile intermediate between the midline of the body and the dorsal profile and disappearing close to the level of the vent. This interpretation is confirmed by the lateral line on the second specimen of *L. bartschi* at hand.

3. Flaps and ridges on the snout. Although Smith & Radcliffe (*in* Radcliffe, 1913) do not mention it in their description, the snout of the holotype of *L. bartschi* does indeed bear flaps. There is a prominent fleshy mound at the tip of the snout bearing six fleshy flaps. Structures which may have been ridges prior to preservation are also present. My second specimen of *L. bartschi* has definite ridges and flaps on the snout.

4. Squamation on the upper part of the suborbital and between the posterior nostril and the eye. On the basis of Smith & Radcliffe's original description and illustration Gosline assumed that these areas lacked scales in *Luciobrotula*. This is actually not the case. Close observation shows the remnants of scale pockets and even a few scales in these areas.

Relationships.—Gosline (1954) postulated the existence of a group of oviparous brotulid genera which are morphologically intermediate between the oviparous genera and the viviparous genera designated by Norman (1939). Of Hawaiian deep-water brotulids, Gosline (1954) assigned *Pycnocraspedum* and *Volcanus* to this group and by inference also included *Luciobrotula*. I quite agree with his suggestions and would go a step farther and place *Petrotyx* (including *Pseudobythites*; see Böhlke, 1955) in this assemblage as well. I defer comment, however, on Gosline's mention of *Brotula* and its similarities to this group.

For the present *Luciobrotula* can be distinguished within this nameless group of genera by the following combination of characters; body elongate; posterior margin of maxillary free, not sheathed; posterior margin of preopercle free, not buried in flesh on the cheek; caudal fin exerted; flaps, ridges and papillae present on head; however, snout, lips and ventral

surface of head not densely covered with prominent papillae; pleural ribs reduced, not prominent elongate structures.

Luciobrotula resembles this group in the following ways; external intromittent organs absent, species probably oviparous; barbels absent; small granular teeth present on premaxillaries, dentaries, vomer and palatines; gill rakers 3; tongue small with a pointed anterior extension; branchiostegal rays 8; body completely covered with small cycloid scales; tip of snout lacking scales; a single lateral line running above the midline of the body; anterior nostril not directly over upper lip but located midway between posterior nostril and tip of snout; vertical fins confluent; each ventral fin with two rays; pectoral fin broadly rounded, supported on a fleshy, fan-shaped, scale-covered base, lacking any free or elongated rays; anterior ribs serve as swimbladder support.

I have examined the following material in preparing the foregoing sections: The holotype and a previously unreported specimen (USNM 179900, Philippines, ALBATROSS station D 5445, 383 fms.) of *Luciobrotula bartschi*, and the holotypes of *Pycnocraspedum armatum* and *Volcanus lineatus* in the U.S. National Museum; specimens of *Petrotyx hopkinsi* and *P. sanguineus* in the U.S. National Museum and Academy of Natural Sciences of Philadelphia; the type material of the new species described below. I am indebted to the curators in Philadelphia and Washington for the opportunity to examine specimens in their collections.

Species.—Three species may be assigned to *Luciobrotula* as defined above. *L. bartschi*, known from two specimens (one the type) from the Philippines; one specimen from the Gulf of Aden (Norman, 1939); and two specimens from Province Tosa, Japan (Kamohara, 1954). *L. lineata* known from a single specimen taken off Hawaii. *L. corethromycter*, hereir described as new, from the Gulf of Mexico, Caribbean, and tropical western Atlantic. These species may be distinguished by use of the following key.

- 1a. Lateral line terminating at about level of origin of dorsal fin; gill rakers stubby, shorter than the vertical diameter of eye; eye 7.0 time in head; ventral fin 1.5 times in head *L. lineata* (Gosline)
- 1b. Lateral line terminating at about level of origin of anal fin; gill raker elongate, longer than vertical diameter of eye; eye 7.9 to 10.9 time in head; ventral fin 1.9 to 3.5 times in head 2
- 2a. Dorsal fin rays 87-89; preventral distance 16.4 to 16.7 per cent of standard length; ventral fin 1.9 to 2.2 times in head; pectoral fin rays 25-26, vertebrae 52. *L. bartschi* Smith & Radcliff
- 2b. Dorsal fin rays 93-103; preventral distance 18.5 to 21.7 per cent of standard length; ventral fin 2.3 to 3.5 times in head; pectoral fin rays 27-29; vertebrae 53-56. *L. corethromycter*, new species

***Luciobrotula corethromycter*, new species**
Figs. 1-5

Material Studied.—HOLOTYPE: USNM 188547, off north coast of Panama: OREGON sta.3586, 9°20'N, 81°24'W, 470-500 fms., 25 May 1962 (534 mm. SL).

PARATYPES.—Gulf of Mexico: USMN 188548, OREGON sta. 3655, 29°10.5'N, 87°56'W, 350-380 fms., 26 July 1962 (295 mm. SL).—USNM 188549, OREGON sta. 4145, 24°25'N, 83°29'W, 300 fms., 14 Dec. 1962 (310 mm. SL).—CNHM 66454, OREGON sta. 4571, 23°04'N, 86°37'W, 400 fms., 7 Dec. 1963 (435 mm. SL).—MCZ 42930, OREGON sta. 4558, 24°25'N, 83°30'W, 300 fms., 2 Dec. 1963 (277 mm. SL).—Panama: USNM 188550, OREGON sta. 3601, 9°07'N, 81°10'W, 400 fms., 31 May 1962 (390 mm. SL).—Guiana: USNM 188551, OREGON sta. 4296, 7°55'N, 53°55'W, 500 fms., 22 March 1963 (500 mm. SL).—USNM 188552, OREGON sta. 4293, 7°14'N, 52°55'W, 400 fms., 21 March 1963 (414 mm. SL).—UMML 13664, OREGON sta. 4300, 7°44'N, 54°19'W, 300 fms. 23 March 1963 (440 mm. SL).

Measurements and Counts.—Given in per cent of standard length, the average first followed by range in parentheses. Preanal 53.2 (50.8-57.0); predorsal 32.1 (30.7-33.1); preventral 20.3 (18.5-21.7); head length 23.7 (22.2-25.0); depth of body at vent 15.1 (13.8-16.9); snout 6.0

TABLE 1.
COUNTS OF THREE SPECIES OF LUCIOBROTULA

	Dorsal fin rays																				
	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103				
<i>bartschi</i>	1	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—				
<i>lineata</i>	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—				
<i>corethromycter</i>	—	—	—	—	—	—	1	—	2	2	2	—	1	—	—	—	—		1		

	Anal fin rays										Pectoral fin rays				
	68	69	70	71	72	73	74	75	76	77	25	26	27	28	29
<i>bartschi</i>		1	—	1	—	—	—	—	—	—		1	1	—	—
<i>lineata</i>		—	—	—	—	—	—	—	—	1		—	—	—	1
<i>corethromycter</i>		—	—	1	2	2	2	1	—	1		—	—	1	7

	Caudal fin rays			Vertebrae				
	10	11	12	52	53	54	55	56
<i>bartschi</i>	—	2	—	2	—	—	—	—
<i>lineata</i>	—	1	—	—	—	1	—	—
<i>corethromycter</i>	3	3	3	—	1	1	3	4



FIGURE 1. *Luciobrotula corethromycter*, paratype, USNM 188550, 390 mm standard length. Drawn by Mildred H. Carrington.

(5.6-6.7); length of upper jaw 12.6 (11.1-14.2); width of expanded posterior portion of maxillary 4.5 (3.7-5.0); pectoral fin length 11.8 (10.6-13.4); ventral fin length 8.2 (7.0-9.0); horizontal diameter of orbit 2.4 (2.2-2.7). Lateral scale rows difficult to count, ranging from about 125 to about 145; other counts given in Table 1.

Description.—Body long, depth at vent 5.9 to 7.2 in standard length but tail not greatly elongated and whiplike. Several specimens have their bellies greatly distended with food or ripe gonads. In all of the specimens examined the head is deflected up and back, and the opercles and branchial membranes are expanded making it difficult to discern the shape of the head. It seems probable, however, that the anterior part of the head is depressed. Dorsal fin originating well behind the nape, over the posterior half or third of the pectoral fin; proximal three-fourths or more of the dorsal and anal fins covered with thick, fleshy, scale-covered skin. The scales on the skin covering the dorsal and anal fins are smaller and less regularly arranged than the scales along the sides of the body. Rays of the caudal fin notably longer than adjacent dorsal and anal fin rays. Pectoral fin short, 1.7 to 2.3 in head, broad and paddle-shaped with a fleshy scale-covered lobed base. Scales extend out about one-half the length of the fin. Each ventral fin with two rays which are united at their bases, outer ray one-half to two-thirds the length of the inner ray; middle rays relatively short, extending only slightly beyond the level of the origin of the pectoral fin. Ventral fin originating well behind the anterior tip of the symphysis of the cleithra, a distance equal to at least the vertical diameter of the orbit.

Body completely covered with small cycloid scales, which extend out onto the distal three-fourths or more of the bases of the dorsal and anal fins and onto the caudal fin. The scales along the body are arranged in regular rows, the scales on the fins are smaller and irregularly arranged. The head also bears small scales; however, the antero-ventral part of the suborbital and the anterior part of the snout are naked (Fig. 2). Scales are present on the expanded, posterior portion of the maxillary along the rami of the lower jaw and on the branchiostegal membranes between the upper four or five branchiostegal rays.

A single lateral line along the side of the body, originating at the upper angle of the opercle and extending posteriorly in a straight line placed about midway between the midline and the dorsal profile of the body. This lateral line extends posteriorly to approximately the level of the vent where it terminates, although a few interrupted segments may be present posteriorly. The lateral line is a fleshy tube which actually overlays the scales (Fig. 3) as Gosline (1954) has described for *L. lineata*. About two dozen pores are present at the ends of the very short branches which are given off both above and below the lateral line. The lateralis



FIGURE 2. *Luciobrotula corethromycter*, holotype, USNM 188547, 534 mm standard length. Dorsal view of head showing squamation, ridges and flaps. Drawn by Mildred H. Carrington.

system also continues onto the head. The lateral canal has a single pore located on a papilla above the gill opening. The supraorbital canal has three pores (two in one specimen); one is located between the fleshy flaps on the upper lip and is difficult to distinguish from a series of deep pits containing pit organs, which are also located between the nose flaps. The other two pores of this series are located along the fleshy ridges on the top of the snout. The infraorbital series most commonly has five pores, with two as elongate slits in the skin of the upper lip beneath the nostrils and the other three along the lower edge of the suborbital. In two specimens there are several additional pores which appear to belong in this series, located lateral to the posterior two pores in the supraorbital series. The preoperculomandibular series has seven or eight pores. Two are located near the tip of the lower jaw, the second is partly fused to its mate on the other side; three, four and five are located along the ramus of the lower jaw; six is located a short distance posterior to the hind margin of the maxillary; seven and eight (sometimes only seven) are located along the hind margin of the preopercle. There are several

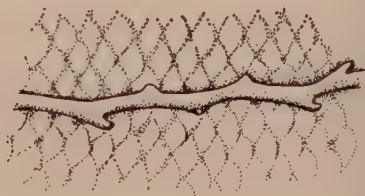


FIGURE 3. *Luciobrotula corethromycter*, paratype, USNM 188550. Section of lateral line. Drawn by Mildred H. Carrington.

series of pit organs on the head; however, they will not be further described in this paper.

Snout depressed, the anterior two-thirds to three-fourths lacking scales. The tip of the snout (Fig. 2) bears a series of broad, fleshy flaps which are overlain by two broad fleshy lappets, one on either side of the snout; the bases of the flaps and the lappet are interspersed with deep pit organs and one of the pores of the supraorbital series. The snout also bears a series of prominent, fleshy ridges which are illustrated in Figure 2. The opercular spine near the upper angle of the opercle is a broad, flattened structure with a rather blunt tip which protrudes through the skin in a few specimens but is buried beneath the skin in the others.

The eye is small; the horizontal diameter, which is greater than the vertical, is 9.1 to 10.3 in the head. The iris is greatly reduced in proportion to the lens.

The posterior nostril is a large, circular opening located at about

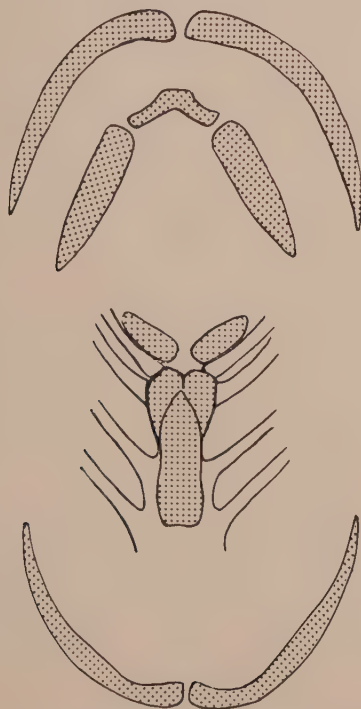


FIGURE 4. *Luciobrotula corethromycter*, holotype, USNM 188547. Diagram of tooth-bearing (stippled) areas in the jaws. Drawn by Mildred H. Carrington.

the midlength of the snout. The tubular anterior nostril is closer to the tip of the snout than to the posterior nostril; it is located at about the level of the posterior nostril, well above the upper lip.

The jaws are large, extending at least an eye diameter beyond the eye. The suborbital sheaths the shaft of the maxillary; however, the broadly expanded posterior end of the bone is free. All teeth (Fig. 4) are small and granular. Wide bands are present on the dentaries, premaxillaries and palatines; the vomerine tooth patch has two widely flaring wings. There are five basibranchial tooth patches; the most anterior and largest is unpaired; it begins at the base of the first gill arch and extends posteriorly almost to the base of the third gill arch. Paired tooth patches are present at the bases of the third gill arches, at the posterior end of the elongate median patch; these two patches and the median patches are very close to each other, separated by only a narrow line of flesh. Another pair of tooth patches is present posterior to the bases of the fourth gill arch. Three pairs of suprabranchial tooth patches are present.

The anterior gill arch (Fig. 5) bears three prominent rakers, one at the angle and two on the lower arm. The arch is paved with patches of granular teeth similar to those on the jaw bones. Each of the three gill rakers also bears granular teeth along its inner surface. The gill filaments are relatively short; filaments opposite the angle of the first gill arch are equal to about three-fourths the diameter of the eye; the filaments on subsequent arches are somewhat longer, being equal to or longer than the vertical diameter of the eye. The pseudobranch is reduced to one or two filaments or is completely absent. The branchiostegal membranes are free from the isthmus and connected to each other for a short distance at their anterior extremes.

There is no evidence of external sexual dimorphism. The gonads are paired in the male. In the female the ovaries are fused medially into a single, bilobed structure. Each lobe is packed with many slender tubes, each of which is packed with eggs. Each tube is flattened distally into a flat membranous plate which is apparently closely appressed to the ovarian membrane.

The anterior three ribs serve as a swimbladder support. Walter R. Courtenay made some observations on the ribs of a female (USNM 188548) which he has allowed me to summarize. The first rib has a strong, thickened leading edge and a flattened tip which is connected with a lateral extension of the *tunica externa* of the swimbladder. The second rib has an extensive, thin, blade-like area behind the thickened leading edge; the medial part of the distal end of this blade-like area supports the swimbladder. The third rib is smaller but similar in structure and function and has a lesser blade-like area. The third rib is the first one to bear an epipleural.

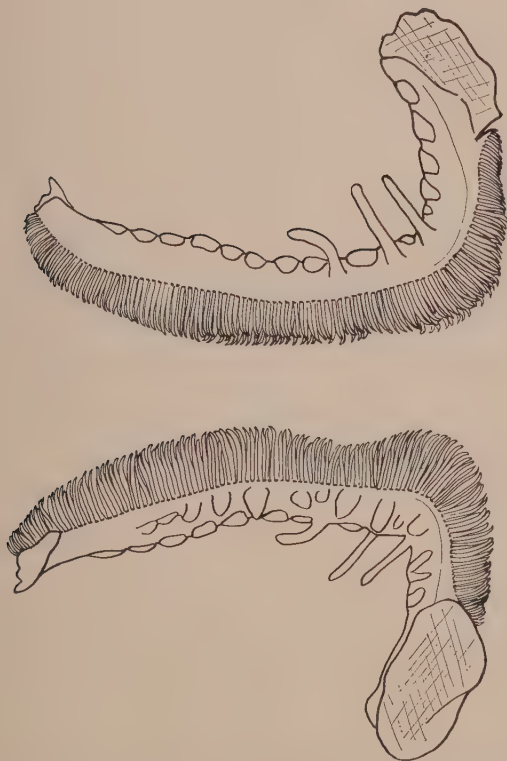


FIGURE 5. *Luciobrotula corethromycter*, paratype, USNM 188552. First gill arch of left side; top figure is lateral view, bottom picture is medial view. Drawn by Mildred H. Carrington.

The anterior projections of the cleithra are loosely held together. The pelvic girdle is joined to the cleithra by a ligament.

The head and most of the body is brown; the belly is darker, as are the extremities of all but the ventral fin. One specimen, USNM 188552, is very pale, and appears to have been dead long before it was preserved.

This species has been taken singly at nine different localities, two off the north coast of Panama, one off Campeche, one off the mouth of the Mississippi, two west of the Florida keys, and three off the Guianas. Depths range from 300 to 500 fathoms. All specimens were taken from a mud bottom.

The specimen from OREGON station no. 4145 contained a partially digested example of the caridean shrimp *Glyphocrangon longleyi* (identified

through the kindness of Dr. Raymond Manning of the U.S. National Museum).

The name *corethromycter* is from the Greek *korethron* (broom) and *mykter* (nose) and alludes to the tuft on the end of the nose.

SUMARIO

UNA REVISIÓN DEL GÉNERO DE PECES *Luciobrotula* CON LA DESCRIPCIÓN DE UNA NUEVA ESPECIE DEL ATLÁNTICO NOR-OCCIDENTAL

El género *Luciobrotula* ha sido conocido previamente por una sola especie de las Filipinas, el Japón y el Golfo de Aden. El género *Volcanus*, de Hawaii, es considerado como sinónimo de *Luciobrotula*. Se diagnostica *Luciobrotula* y sus relaciones con *Pycnocraspedum* y se discute *Petrotyx*. Estos tres géneros comprenden un pequeño grupo de especies probablemente ovíparas, que morfológicamente son intermedias entre un gran grupo de formas ovíparas, y un gran grupo de formas vivíparas.

Se da una descripción nueva de *Luciobrotula* de la región tropical del Atlántico Occidental. Se tomaron ejemplares de fondos fangosos a profundidades de 300 a 500 brazas en localidades del Golfo de México, del Caribe, en el área de Panamá y de las Guayanas.

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FISHES OF THE NORTHERN SEAS OF THE USSR. By A. P. Andriashev. Fauna of the USSR No. 53, Zool. Inst. Akad. Nauk SSSR, 1954. Translated from the Russian by Michael Artman. Available from the Office of Technical Services, U. S. Department of Commerce, Washington, D. C. as OTS 63-11160, 617 pp., 300 figs., paperbound. \$6.25.—The Russian edition of this important book has been reviewed in *Copeia* (1955:312-313) by Robins and Walters. As is frequent in this series of translations, many of the figures are of poor quality. This is in part due to the difficulties of reproducing the figures but the problem is compounded by the reduction in size from the original. Fortunately, the actual size of the specimens is given in the original so the change in size of the figures will not cause confusion as it has in translations where reductions were given as $\times \frac{1}{4}$, etc. The paper is rather thin and does not give promise of long life. The quality of the translation seems quite good from a cursory comparison with several sections of the original.—BRUCE B. COLLETTE, *Bureau of Commercial Fisheries Ichthyological Laboratory, U. S. National Museum, Washington, D. C. 20560.*

SEPARATE

OF A PAPER PUBLISHED BY

THE INTERNATIONAL TRUST FOR ZOOLOGICAL NOMENCLATURE

ON BEHALF OF

THE INTERNATIONAL COMMISSION ON ZOOLOGICAL NOMENCLATURE

This paper contains an application relating to a question of zoological nomenclature which has been submitted to the International Commission on Zoological Nomenclature for decision. As a preliminary, this paper has been published in the "Bulletin of Zoological Nomenclature". The volume in which this paper was so published and the date of publication are shown at the foot of the first page of the paper.

2. The object of publishing applications in the "Bulletin of Zoological Nomenclature" is to provide an opportunity to interested specialists to submit comments to the Commission on the action recommended in the applications so published. For this purpose an interval of six months from the date of publication is allowed to elapse before the International Commission starts to vote on any given application.

3. One of the principal objects of the International Trust for Zoological Nomenclature in providing authors with separates (off-prints) of applications published in the "Bulletin" is to secure a rapid and wide distribution of those applications among interested specialists, in order to provide to those specialists an opportunity of commenting upon the applications in question before a decision is reached by the International Commission.

4. Recipients of separates of papers published in the "Bulletin" are therefore particularly requested to furnish their comments on the action proposed as soon as possible to the Assistant Secretary, the International Commission on Zoological Nomenclature, c/o British Museum (Natural History), Cromwell Road, London, S.W.7, England.

THUNNUS SOUTH, 1845 (PISCES): PROPOSED VALIDATION UNDER
THE PLENARY POWERS. Z.N.(S.) 1652

By Bruce B. Collette (*Bureau of Commercial Fisheries Ichthyological Laboratory,
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and

Robert H. Gibbs, Jr. (*U.S. National Museum, Washington, D.C., U.S.A.*)

The generic name *Thunnus* was proposed by South (1845, *Encycl. Metrop.* 25 : 620) as an emendation of [substitute for] *Thynnus* Cuvier (1817, *Règne Animal* 2 : 313), type-species by tautonymy, *Scomber thynnus* Linnaeus (1758, *Syst. Nat.* (ed. 10) 1 : 297–298), which is preoccupied by *Thynnus* Fabricius (1775, *Syst. Ent.* : 360) in Hymenoptera. Since this proposal by South was pointed out by Gill (1894, *Proc. U.S. Nat. Mus.* 16 : 693–694), most workers have used *Thunnus* South at least for the type-species. Within recent years numerous authors, including Fraser-Brunner (1950, *Ann. Mag. nat. Hist.* 12 : 142–146), Rivas (1951, *Bull. mar. Sci. Gulf and Carib.* 1 : 217–223), de Sylva (1955, *Bull. mar. Sci. Gulf and Carib.* 5 : 31–40), Collette and Gibbs (1963, *FAO Fish Rept.* 6, 1 : 27–28) and Gibbs and Collette (MS, Comparative anatomy and systematics of the tunas, genus *Thunnus*), have used *Thunnus* South for six commercially important species of tunas: *T. alalunga* (Bonnaterre, 1788), *T. albacares* (Bonnaterre, 1788), *T. atlanticus* (Lesson, 1830), *T. obesus* (Lowe, 1839), *T. thynnus* (Linnaeus, 1758), and *T. tonggol* (Bleeker, 1852). The World Scientific Meeting on the Biology of Tunas and Related Species, sponsored by the Food and Agriculture Organization of the United Nations and held in La Jolla, California from June 2–14, 1962, suggested (*FAO Fish Rept.* 6, 1 : 8) that the generic nomenclature utilized by Collette and Gibbs (*op. cit.*) be tentatively accepted pending future revisionary studies.

2. In 1955, Whitley (*Proc. Roy. zool. Soc. N. S. Wales*, 1953–54 : 51–52) published the rediscovery of *Thinnus* S.D.W. (1837, *Analyst* 18 : 208), an emendation of *Thynnus* Cuvier, 1817, which antedates *Thunnus* South, 1845 by eight years, and proposed that *Thinnus* S.D.W., be employed in place of *Thunnus* South. S.D.W., perhaps S. D. Wood, of Derbyshire according to Whitley, wrote systematic lists of the animals of Britain for the *Analyst* emending many scientific names by changing ph into f, y into i, etc. As far as we can determine, *Thinnus* S.D.W. has been used only by Abe (1955, *Bull. Jap. Soc. Sci. Fish.* 21 : 20–23). Later (1963) Abe employed *Thunnus* for *T. thynnus* in his encyclopedia of Japanese marine fishes (Genshoku Gyorui Kewsaku Zukan).

3. The tunas of the genus *Thunnus* are important commercial species. Because most studies of the tunas are made by fishery biologists, not by systematists, any change in nomenclature would adversely affect many biologists.

4. Therefore, we request the International Commission to:

- (1) exercise its plenary powers to suppress the generic name *Thinnus* S.D.W., 1837, for the purposes of the Law of Priority but not for those of the Law of Homonymy;

- (2) to place the generic name *Thunnus* South, 1845 (gender : masculine), type-species through *Thynnus* Cuvier, 1817, by tautonymy, *Scomber thynnus* Linnaeus, 1758, on the Official List of Generic Names in Zoology;
- (3) place the specific name *thynnus* Linnaeus, 1758, as published in the binomen *Scomber thynnus*, (type-species of *Thunnus* South, 1845) on the Official List of Specific Names in Zoology;
- (4) place the following generic names on the Official Index of Rejected and Invalid Generic Names in Zoology;
 - (a) *Thynnus* Cuvier, 1817 (a junior homonym of *Thynnus* Fabricius, 1775);
 - (b) *Thinnus* S.D.W., 1837 (as suppressed under the plenary powers in (1) above);
- (5) to place the family-group name THUNNINAE E. C. Starks, 1910 (*J. Morph.* 21(1) : 79–80) (type-genus *Thunnus* South, 1845) on the Official List of Family-Group Names in Zoology;
- (6) to place the family-group name THINNINAE G. P. Whitley, 1955 (type-genus *Thinnus* S.D.W., 1837) (invalid because the name of its type-genus has been suppressed under the plenary powers) on the Official Index of Rejected and Invalid Family-Group Names in Zoology.

Changes in Glycogen and Lactate Levels in Migrating Salmonid Fishes Ascending Experimental "Endless" Fishways^{1,2,3}

BY ANNE R. CONNOR, CARL H. ELLING, EDGAR C. BLACK, GERALD B. COLLINS,
JOSEPH R. GAULEY AND EDWARD TREVOR-SMITH

ABSTRACT

Certain aspects of the performance and biochemistry of adult migrating salmonid fishes were investigated during ascents of 1:16- and 1:8-slope experimental fishways which employed locking devices permitting the simulation of fishways of any length. Fish tested were chinook salmon (*Oncorhynchus tshawytscha*), sockeye salmon (*O. nerka*) and steelhead trout (*Salmo gairdneri*) diverted from their upstream migration on the Columbia river at the Bonneville dam fishways during the summer of 1959. Blood and muscle lactate, and muscle and liver glycogen levels were determined in control fish, and in fish following three types of activity. Records of individual performance were kept.

All species were willing to enter and capable of ascending fishways of either slope up to 1000 ft in height under favourable hydraulic conditions. Blood lactate and muscle glycogen determinations revealed the degree of exercise to be moderate even during prolonged ascents. Moderately high ascents (about 100 ft) in the steeper fishway apparently required the expenditure of some muscle glycogen whereas similar ascents in the 1:16 fishway did not. When muscle glycogen was utilized during prolonged ascents the expenditure appeared to be progressive. All species were apparently able to adapt to prolonged ascents of either fishway. Certain fish of each species tended to stop moving of their own volition in both fishways. After a 60-min volitional stop some evidence of recovery from the effects of exercise was observed. Discussion of the above data is presented.

INTRODUCTION

THE PRIMARY PURPOSES of the investigations were to study the behaviour and performance of salmonid fishes in fishways, and to determine the feasibility of using fishways of steeper than normal slope. The fishway slope accepted as standard on mainstem Columbia river dams until recently was 1:16 (i.e. 1 ft, or 30.5 cm, rise in 16 ft, or 4.88 m, of length). One exception is the 1:10-slope fishway system at Rock Island dam which has been in operation since 1933. The use of a 1:10- or 1:8-slope in new fishways could, under certain conditions, substantially reduce the costs of fishway construction.

Although many studies have been made on the effects of severe exercise on fish, very few have been carried out on fish subjected to moderate exercise. The experiments planned in order to study the effects of fishway design on swimming performance presented the opportunity to collect extensive data on the biochemistry of adult fish during moderate sustained exercise.

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²Contribution from the Department of Physiology, University of British Columbia, Vancouver, Canada, and the Bureau of Commercial Fisheries, Fish-Passage Research Program, Seattle, Washington, U.S.A.

³The project was supported by grants from the National Research Council of Canada, the British Columbia Electric Company, Vancouver, Canada, and the U.S. Army Corps of Engineers.

Experiments were conducted at the Fisheries-Engineering Research Laboratory operated by the Bureau of Commercial Fisheries of the U.S. Fish and Wildlife Service in conjunction with the U.S. Army Corps of Engineers⁴ at North Bonneville, Washington, during 1958 and 1959.

In 1958, the work was primarily directed to studying the performance of salmon and trout in fishways of both 1:16- and 1:8-slope, and to determining the hydraulic conditions best suited to the passage of these fish in a 1:8 fishway. Preliminary studies on the biochemistry of fishes ascending both fishways were carried out. The results of the 1958 experiments have been published in detail by Collins *et al.* (1963). In summary, their conclusions were: (1) that the 1:8 fishway is as suitable for the passage of chinook salmon (*Oncorhynchus tshawytscha*), sockeye or blueback salmon (*O. nerka*), and steelhead trout (*Salmo gairdneri*) as is the conventional 1:16 fishway provided the proper hydraulic conditions are attained; (2) that the ability of these fishes (particularly chinook salmon) to pace themselves in a 1:8-slope fishway is dependent on the hydraulic conditions; and (3) that under the proper conditions, the ascent of either fishway constitutes only moderate exercise for salmonid fishes.

The 1959 studies which are reported here were designed to give more complete information on the biochemical aspects of the ascent of fishways by salmonid fishes under controlled conditions.

A report has been published by Collins *et al.* (1962) on the ability of salmonids to ascend extended fishways of 1000 ft or more. The report embodies some of the results from the 1959 studies. They concluded that high fishways are suitable for the passage of chinook, sockeye and steelhead under the conditions tested, and that the degree of muscular effort involved, as judged by the blood lactate response, is only moderate. No evidence of fatigue was found on the basis of either performance or blood lactate levels.

Studies by several workers (reviewed by Black *et al.*, 1961) have revealed that severe fatigue in fishes is accompanied by a marked and prolonged elevation of the blood and muscle lactate and pyruvate levels, and by a reduction of the muscle glycogen level. It has been concluded that, during strenuous exercise, fish rely primarily on the anaerobic breakdown of muscle glycogen to supply the energy for muscular contraction. The overall pattern is similar to that observed in mammals including man, but the time course of lactate removal from the blood and of restoration of muscle glycogen in certain fishes is extremely protracted when compared with warm-blooded animals. Black *et al.* (1962) postulated that inadequacy of tissue oxygenation due to several factors, including a possible impairment of circulation following severe exercise, may contribute to the delay in removal of lactate. Muscle glycogen appears to be restored in immature trout following severe exercise only when they are feeding. However Fontaine and Hatey (1953) observed that in migrating, non-feeding Atlantic salmon (*S. salar* L.) ascending the Adour river the total stores of carbohydrate

⁴Research financed by the U.S. Army Corps of Engineers as a part of a broad program of Fisheries-Engineering Research for the purpose of providing design criteria for fish-passageway facilities at Corps projects on the Columbia river.

Although redistributed throughout the body, remained more or less constant. They attributed this maintenance of carbohydrate reserves, despite the expenditure of considerable muscular effort, to an increased rate of conversion of lipid and protein to carbohydrate.

Controlled biochemical studies on moderate exercise in fishes are not very numerous nor complete since recovery patterns have not yet been fully investigated. In rainbow trout (*S. gairdneri*) following 30 min cruising in a rotating chamber, the blood lactate level is elevated approximately 3-fold, and the muscle glycogen may or may not be reduced (Black, 1957a; Black *et al.*, 1960 and 1962).

In the present studies on chinook and sockeye salmon and steelhead trout, blood and muscle lactate, and muscle and liver glycogen were measured in control fish, and in fish following ascents of various durations in both the 1:8 and 1:16 fishways in an attempt to determine the degree of muscular effort and fatigue which was involved.

METHODS AND MATERIALS

The fish used in the experiments were of three species: chinook salmon (*Oncorhynchus tshawytscha*), sockeye salmon (*O. nerka*) and steelhead trout (*Salmo gairdneri*). These fish were in the maturing, or fully mature, state and were diverted from their upstream migration 140 river miles (225.3 km) from the mouth of the Columbia river at the Washington-shore fishway of Bonneville dam.

The physical design of the laboratory and the experimental "endless" fishways has been described in detail by Collins *et al.* (1963). A brief resumé is given here.

In all procedures involving the passage of fish, the only stimulus employed was the apparently natural instinct of spawning salmonids to swim upstream against a current. The fish entered the laboratory collection pool at an elevation of 50 ft (15.24 m) above mean sea level. Fish showing obvious signs of recent severe injury or ill health were rejected. Most of the fish used in 1959 were held in the collection pool for 1-6 hr before testing. A small group of sockeye salmon was held overnight before use.

The design of the "endless" fishways is illustrated in Fig. 1. Each fishway comprised a circuit of 16 pools including 2 turn pools and a lock connecting the highest pool with the lowest, thus making possible the simulation of a fishway of any length. The fishway construction was of the pool-and-overfall type without submerged orifices. The dimensions of the pools were 3 ft (91.4 cm) in width, and 8 or 16 ft (2.44 or 4.88 m) in length depending on the fishway slope. The freeboard was 3 ft (91.4 cm) and the average water depth was 6.8 ft (2.07 m). The rise between pools was 1 ft (30.5 cm). The turn pools were coved and, because of the tendency of fish to use them as rest areas, were provided with a grill which limited the available depth to 2 ft (61.0 cm), and a system of floor baffles which created a turbulent, rapidly flowing water pattern. Lock pools in both fishways were 8 ft (2.44 m) in length, 23 ft (7.01 m) deep when filled and 7 ft (2.13 m) deep when emptied. The time required to empty the lock was approximately 30-40 sec. Refilling of the lock required about 1 min and was accomplished after a fish had left the lock pool on another circuit of the fishway.

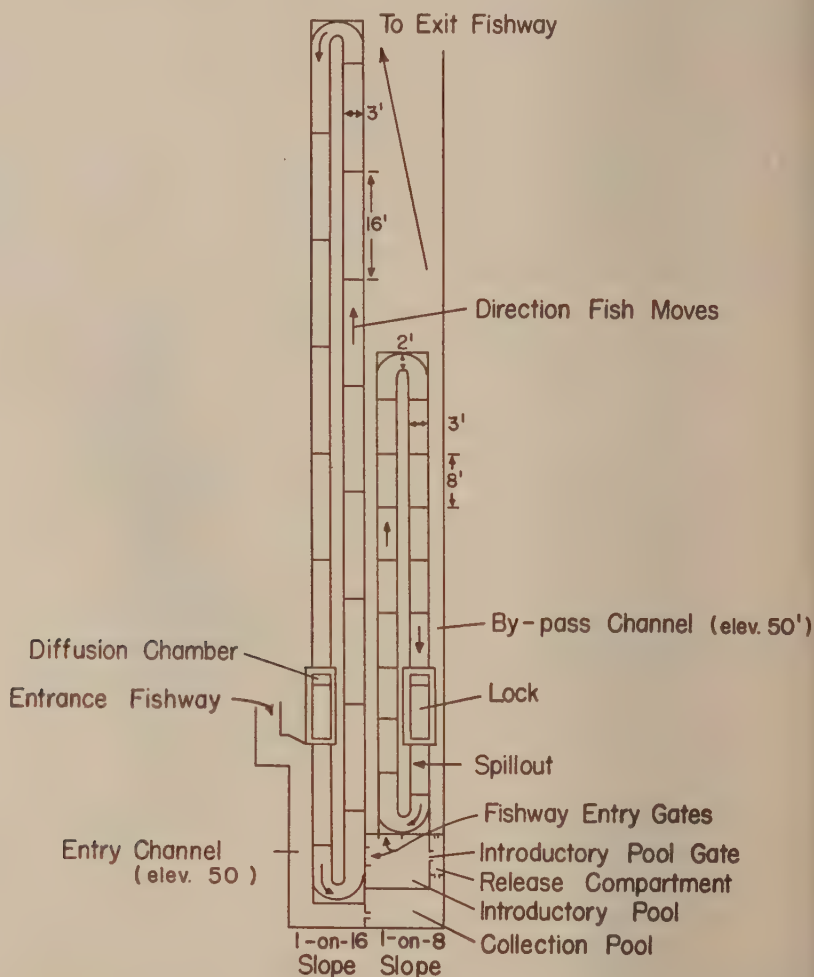


FIG. 1. Plan view of the 1:16- and 1:8-slope experimental "endless" fishways with auxiliary approach channels and pools. Bonneville, 1958-9. (Diagram courtesy of Bureau of Commercial Fisheries, Seattle.)

In the original design of the fishways, the weir crests were 3 ft (91.4 cm) long and 2 inches (5.08 cm) wide. During the 1958 experiments, it was found that many of the chinook salmon tended to ascend rapidly in the straight portions of the 1:8 fishway and rest in the turn pools (Collins *et al.*, 1963). When rest areas were eliminated by introducing a turbulent flow in the turn pools as described above, the chinook became unduly fatigued or stopped moving. Tests showed that the following modification in design provided more favourable hydraulic conditions. The weirs on the 1:8-slope fishway were restricted to

$\frac{1}{2}$ inches (67.3 cm) by alternating baffles (Fig. 2) and, as a result, the turbulence each pool was considerably reduced, and a definite lateral component was introduced into the flow pattern thus enabling the fish to rest during the ascent. The 1:16 fishway retained full 3-ft (91.4-cm) wide weir crests throughout 1958 and 1959.

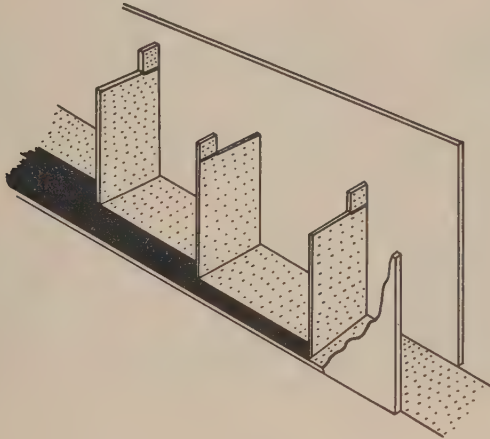


FIG. 2. Diagram of the 1:8-slope experimental "endless" fishway construction showing arrangement of alternate baffles to restrict the weir crests. Bonneville, 1958. (Diagram courtesy of Bureau of Commercial Fisheries, Seattle.)

With a single exception, both fishways remained structurally unchanged in 1959 from the conditions prevailing at the conclusion of the 1958 experiments. The minor change referred to consisted of a vertical stabilizer which was attached at right angles to each weir baffle in the 1:8-slope fishway only (Fig. 3 and 4). These stabilizers extended approximately 12 inches (30.5 cm) upstream and downstream into each pool. Their purpose was to reduce the draw-down of water over the weirs, and also to diminish the substantial air space beneath the weir overfall, thus providing more water depth for passage of large fish over the weir. The actual effect of the changed hydraulics on fish movement was not established in these tests, however, there was a possibility that the blind pocket created on the downstream side of each weir (Fig. 4) may have delayed the movement of some fish in this fishway.

The setting of the heads on the weirs, measured 4 ft (1.22 m) upstream of the weir crests, was 0.8 ft (24.4 cm), and a plunging flow was maintained with the non-orifice condition.

Fish were sampled from the holding pool in the control state, and from each fishway in 3 different conditions of exercise. The *control* fish were dipped from the holding pool or identification chamber 1–6 hr after entry, and were considered to be in a relatively unexercised state. The largest experimental group consisted



FIG. 3. View up the 1:8-slope experimental "endless" fishway showing the alternate baffle arrangement on weir crests, and the placement of the vertical stabilizers. Bonneville, 1959. (Photograph courtesy of Bureau of Commercial Fisheries, Seattle.)



FIG. 4. View from above of a weir crest in the 1:8-slope experimental "endless" fishway showing the blind pocket created on the downstream face by the vertical stabilizer. Bonneville, 1959. (Photograph courtesy of Bureau of Commercial Fisheries, Seattle.)

of fish of each species which were sampled immediately upon entry into the 104th pool of either fishway (*104-pool terminated*). This standard ascent of 104 pools was arbitrarily chosen for its convenience (i.e. the upper turn pool on the 10th circuit of either fishway), and because it approximates the length of ascent in many existing fishways at low-head dams in the Columbia river basin. Another smaller group of fish of each species was sampled after completing various numbers of pools between 104 and 1000 in either fishway (*long-run terminated*). In both of the terminated treatments, the fish were considered to be in an actively moving state at the time of sampling. Under the hydraulic conditions described, a number of fish of each species showed a tendency to stop moving of their own volition and to remain in one pool for a considerable length of time during ascents of both fishways. These were called *volitional-stop* fish, and were sampled after they had remained for 60 min in any one pool. (A few fish were also sampled after a 30-min stop.) The volitional fish were considered to be in an inactive or recovery state at the time of sampling.

Sampling of fish was carried out as follows. The fish was lifted from the terminal pool with a dip net, stunned and carried quickly to the working area where it was placed ventral side uppermost in a V-shaped trough. The time required for this stage of sampling ranged from 10–35 sec except where difficulty was encountered in netting.

A blood sample of 2 ml was obtained by cardiac puncture, and transferred into a tube containing 18 ml of cold 10% trichloroacetic acid (TCA). After mixing, the filtrate was collected in a 1-oz polyethylene bottle in which it was stored in the frozen state until analyzed for lactate.

A muscle core was obtained with a punch from the left side of the fish between the lateral line and dorsal fin. Skin and scale were removed and the sample was divided into two portions and dropped into a freezing mixture of 95% ethanol and dry ice. The abdomen was opened and a liver sample of 1–2 g was removed and placed in the freezing mixture. Muscle and liver samples were kept frozen until extracts were prepared, in some cases overnight. In one series of experiments on chinook salmon, an additional muscle core was removed from a position near the tail of the fish for purposes of comparison.

For lactate determination, frozen muscle samples of approximately 2 g were weighed rapidly and placed in 18 ml of cold 10% TCA. A homogenate was prepared by grinding for 5 min in a Servall Omni-Mixer with the cup immersed in ice-water. The homogenate was then filtered and frozen as for blood.

For glycogen determination, frozen samples of muscle and liver (1–5 g) were weighed and dropped into 6 ml of hot 60% KOH. After 2 hr in a boiling water bath, the digests were transferred quantitatively while still hot to 1-oz bottles, using 10–15 ml of distilled water for rinsing. Digests were stored at room temperature.

Muscle and blood lactate were determined in the TCA filtrates by the method of Barker and Summerson (1941). Muscle and liver glycogen were determined in the KOH digests following dilution to a standard volume with distilled water and precipitation in 65% ethanol with the addition of Na_2SO_4 . The phenol-

sulphuric acid method of Montgomery (1957) was used for glycogen determinations of chinook and sockeye samples, and the anthrone method as described by Carroll *et al.* (1956) was used for steelhead samples.

Fishway water temperatures, measured daily, ranged from 56 to 70°F (13.3–21.1°C) throughout the 3 months of the experiment (June 2 to September 2, 1959). These temperatures were slightly lower than those prevailing during the 1958 experiments discussed by Collins *et al.* (1963).

The body weight of each fish was recorded. Accurate records were kept of the duration of each ascent and of the individual time per pool for every fish. Other measurements included daily water turbidity, and fork length and gonad weight of each fish. These latter data are not discussed in the present paper, since no correlation was found between observed variations and the biochemical properties under consideration.

Standard error of the mean was calculated for each condition, and is recorded in the tables. Where comparisons were made between means, Snedecor's "F" test for homogeneity of variance was applied to the mean squares of each group ($F = \text{greater mean square/lesser mean square}$; Snedecor, 1956, p. 96). Where the variances proved to be homogeneous at the 5% level, a standard Fisher "t" test was applied to estimate the probability of a significant difference between means (Snedecor, 1956, pp. 87–91). In many cases, where the treatments appeared to have affected the standard deviations of the sample groups, as shown by an F value exceeding the 5% level, "t'" was calculated from the formula $t' = (\bar{x}_1 - \bar{x}_2) / s \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}$ and the 5% probability level of "t'" was estimated by Cochran's approximation (Snedecor, 1956, pp. 97–99). A probability of a larger value of "t'" or "t'", sign ignored, of 5% (0.05) or less was considered to be significant.

METHODOLOGY

RESULTS

Results of a comparison of lactate and glycogen levels in muscle cores taken near the tail with those in cores taken from the usual position below the dorsal fin are presented in Table I. Samples were obtained from chinook salmon upon

TABLE I. Comparison of lactate and glycogen levels in muscle cores taken from the "front" and the "back" positions of migrating Columbia river chinook salmon (*O. tshawytscha*) sampled after ascents of 104 pools (104 ft) in the experimental fishways. Bonneville, 1959.

		Muscle lactate		Muscle glycogen	
		Front	Back	Front	Back
		mg/100 g	mg/100 g	%	%
1:16-slope	Mean $\pm$ SE	315 $\pm$ 31.1	324 $\pm$ 31.3	0.154 $\pm$ 0.0275	0.190 $\pm$ 0.0387
	No. of fish	(7)	(7)	(7)	(7)
	Range	192–421	225–459	0.079–0.304	0.094–0.331
1:8-slope	Mean $\pm$ SE	413 $\pm$ 55.8	332 $\pm$ 48.2	0.126 $\pm$ 0.0139	0.153 $\pm$ 0.0205
	No. of fish	(4)	(4)	(4)	(4)
	Range	247–475	257–470	0.089–0.154	0.106–0.203

TABLE II Mean sampling times, the standard error of the means and the range of sampling times (in seconds) measured from the time of capturing fish. Data are for migrating Columbia river chinook salmon (*O. tshawytscha*), sockeye salmon (*O. nerka*) and steelhead trout (*S. gairdneri*) taken from the holding pool (controls), from the experimental fishways during active ascent (terminated), and from the experimental fishways after a 60-min stop (volitional). Bonneville, 1959.

			Chinook			Sockeye			Steelhead		
			Blood	Muscle	Liver	Blood	Muscle	Liver	Blood	Muscle	Liver
Controls	Mean $\pm$ SE	73.8 $\pm$ 6.48	108.1 $\pm$ 7.33	126.0 $\pm$ 8.43	50.1 $\pm$ 2.31	72.5 $\pm$ 2.91	82.3 $\pm$ 3.57	72.2 $\pm$ 5.33	95.6 $\pm$ 5.93	104.5 $\pm$ 6.29	
	No. of fish	35	35	35	21	22	22	25	25	24	
	Range	43-200	59-220	71-233	32-90	53-110	61-130	46-171	63-200	76-210	
Terminated (all conditions)	Mean $\pm$ SE	61.2 $\pm$ 4.08	91.8 $\pm$ 4.65	107.4 $\pm$ 5.14	43.0 $\pm$ 4.24	66.3 $\pm$ 4.39	75.1 $\pm$ 4.37	51.8 $\pm$ 2.70	74.0 $\pm$ 3.01	83.1 $\pm$ 3.27	
	No. of fish	80	81	81	46	46	46	86	88	88	
	Range	29-235	45-270	52-298	26-220	45-240	51-245	24-182	42-209	46-217	
Volitional (all conditions)	Mean $\pm$ SE	72.4 $\pm$ 5.04	112.4 $\pm$ 6.81	129.2 $\pm$ 7.39	43.0 $\pm$ 2.46	64.9 $\pm$ 3.62	74.6 $\pm$ 4.56	68.2 $\pm$ 7.58	96.6 $\pm$ 8.58	108.7 $\pm$ 9.60	
	No. of fish	30	30	30	14	14	14	21	22	22	
	Range	35-167	50-225	56-240	29-53	45-90	49-107	34-150	55-180	60-210	

completion of ascents of moderate length (104 ft) in both fishways. Differences in muscle lactate and muscle glycogen levels between "front" and "back" core samples were not significant. There was no evidence that the degree of muscular contraction was greater near the tail of the fish during swimming. In fact, the ratio of lactate to glycogen was actually lower in the "back" core than in the "front". These findings are similar to those observed in 1½-year-old rainbow trout by Black *et al.* (1962) who concluded that no appreciable error would result from the routine use of the "front" position for sampling.

The average times taken to sample blood, muscle and liver in each species in the control, terminated and volitional conditions are shown in Table II. The shortest sampling times were recorded for the terminated conditions (both 104-pool and long-run) mainly because the fish were easier to reach and closer to the working area than those in the holding pool or those that stopped volitionally in certain areas of the fishways. It is also possible that fish terminated during active ascent struggled less upon capture than those in the control state or after 60 min in one pool.

CONTROL FISH

BLOOD LACTATE. Blood lactate for the control chinook salmon averaged 17.8 mg per 100 ml blood (mg%); the average for sockeye (blueback) salmon was 17.4 mg%; and the average for steelhead trout was 12.2 mg% (Table III). These values are somewhat higher than most of those reported by other workers for various species of fish (Black *et al.*, 1961, table VIII). The slightly higher value noted here for salmon as compared with trout is in keeping with the observations referred to above.

Blood lactates for the control fish probably represent values higher than those for the completely unexercised condition. The previous history and degree of activity in the holding pool for individual fish are not known. The flow of water used to stimulate fish to enter the experimental fishways frequently rendered all fish in the holding pool more active. Sockeye salmon which had been held overnight showed a significantly lower ($0.025 > P > 0.01$) blood lactate value (10.9 ± 1.44 mg%) than fresh fish which had been held 1–6 hr (19.5 ± 1.99 mg%). The lowering of blood lactate levels may be attributed to the longer holding period and the absence of disturbance during the night, together with a probable nocturnal reduction in metabolism and activity. Similar tests in 1958 failed to show any difference between lactate levels of fresh and heldover chinook salmon (Collins *et al.*, 1963).

The amount of struggling during netting and the completeness of stunning after capture undoubtedly varied between fish. However, no correlation was found between the sampling times (Table II) and the blood lactate values on an individual basis, probably because of the multiplicity of factors in this situation which may influence the lactate level. The values are presented as controls for subsequent experiments and are not intended to represent the true blood lactate levels for unexercised fish.

TABLE III. Body weights and levels of blood and muscle lactate, and muscle and liver glycogen in migrating Columbia river chinook salmon (*O. tshawytscha*), sockeye salmon (*O. nerka*) and steelhead trout (*S. gairdneri*) taken from the holding pool in the control state. Bonneville, 1959.

	Body weight	Lactate		Glycogen	
		Blood	Muscle	Muscle	Liver
Chinook	<i>kg</i>	<i>mg%</i>	<i>mg/100 g</i>	<i>%</i>	<i>%</i>
	Mean $\pm$ SE No. of fish Range	17.8 $\pm$ 1.37 35 5.7-38.5	394 $\pm$ 17.3 35 238-600	0.127 $\pm$ 0.0101 35 0.053-0.346	0.69 $\pm$ 0.101 35 0.04-2.62
	Male mean (<i>n</i>) Female mean (<i>n</i>)	15.3 (17) 20.1 (18)	385 (17) 402 (18)	0.123 (17) 0.131 (18)	0.99 (17) 0.42 (18)
Sockeye	Mean $\pm$ SE No. of fish Range	17.4 $\pm$ 1.74 21 5.5-35.8	391 $\pm$ 23.7 22 219-574	0.086 $\pm$ 0.0063 22 0.037-0.151	0.61 $\pm$ 0.105 22 0.04-1.64
	Male mean (<i>n</i>) Female mean (<i>n</i>)	18.6 (9) 16.6 (12)	394 (9) 390 (13)	0.100 (9) 0.076 (13)	1.03 (9) 0.31 (13)
	Fresh (held 1-6 hr) mean (<i>n</i>) Held overnight mean (<i>n</i>)	19.5 (16) 10.9 (5)	391 (17) 393 (5)	0.086 (17) 0.087 (5)	0.52 (17) 0.89 (5)
Steelhead	Mean $\pm$ SE No. of fish Range	12.2 $\pm$ 0.87 25 4.9-19.9	416 $\pm$ 19.4 25 290-665	0.079 $\pm$ 0.0055 25 0.035-0.134	1.31 $\pm$ 0.197 25 0.18-4.78
	Male mean (<i>n</i>) Female mean (<i>n</i>)	12.5 (7) 12.2 (18)	450 (7) 403 (18)	0.068 (7) 0.083 (18)	2.19 (7) 0.97 (18)

MUSCLE LACTATE. The average muscle lactate values for control fish were as follows: chinook salmon, 394 mg/100 g wet tissue; sockeye salmon, 391 mg/100 g; and steelhead trout, 416 mg/100 g (Table III). There was no significant difference between the values for fresh sockeye and those held overnight.

These values are much higher than those reported in the literature for unexercised fish (Nakatani, 1957; Leivestad *et al.*, 1957; Tomlinson *et al.*, 1961; Fraser *et al.*, 1961; Black *et al.*, 1962). The values are in fact similar to those reported by most of these authors for severely exercised or exhausted fish. However, the data of Tomlinson *et al.* (1961), for sockeye which had been commercially netted both at sea and in fresh water, and were probably exhausted, show lactate levels 100–200 mg/100 g higher than those in the control sockeye studied here.

There are several factors which may contribute to the high muscle lactate levels in these experiments. The average sampling times for muscle ranged from 72.5–108.1 sec (Table II). A time curve for the production of muscle lactate during strenuous exercise prepared by Black *et al.* (1962) for rainbow trout indicates that muscle lactate had reached over $\frac{3}{4}$ of its eventual maximum value within the first 2 min, whereas blood lactate had risen to only $\frac{1}{2}$ of its eventual peak value in the same period. The increase in blood lactate is delayed due to the time required for diffusion from muscle. Thus a large part of the muscle lactate found in the present experiments could have been generated during the sampling interval before the blood level had risen appreciably, especially since blood samples were taken first. Severe struggling of the fish during capture and stunning could contribute significantly to this increase in muscle lactate. Other factors which may have influenced the muscle lactate levels are the age and endocrine status of the fish, the recent environmental change from salt to fresh water, the relatively high water temperatures in the river, and the initial levels of the precursor, muscle glycogen.

High muscle lactate values were observed throughout the entire experiment and no significant differences appeared in any of the 104-pool, long-run or voluntary groups in response to exercise, despite significant alterations in blood lactate and muscle glycogen. Muscle lactate data are included in the tables but are not discussed further since they do not appear to be meaningful in terms of these experiments.

MUSCLE GLYCOGEN. The average levels of muscle glycogen in control fish were as follows: chinook 0.127 g/100 g wet tissue (%); sockeye, 0.086%; and steelhead, 0.079% (Table III). These values fall within the ranges reported for various species of fish in the literature (reviewed by Black *et al.*, 1961, and Tomlinson and Geiger, 1962), but appear somewhat low for adult fish. Earlier studies (Greene, 1921; and Fontaine and Hatey, 1953) reported low levels of 0.01–0.15% in adult salmon at the start of the spawning migration, however the methods of capturing and sampling employed were such that considerable loss of glycogen through struggling or autolysis could have occurred. Black *et al.* (1960) reported an average level of 0.378% in spawning Kamloops trout even without the use of quick-freezing techniques. Various studies of the *post-mortem* increase in muscle lactate such as those of Tomlinson *et al.* (1961)

indicate that the initial level of the precursor may have been considerably higher. These studies however should be interpreted cautiously since Tarr and Leroux (1962) have shown the existence of other intermediary metabolites in fish muscle capable of resulting in lactate formation. The factors mentioned above as tending to increase the control blood and muscle lactate levels during sampling would also lower the muscle glycogen levels. In view of the high muscle lactate levels, it is indeed probable that all muscle glycogen levels reported here are somewhat low. However, it was still found possible to demonstrate statistically significant changes in the muscle glycogen in response to exercise in most of the experimental situations, although the relative difficulty in sampling and the probability of greater struggling in control fish may have resulted in less apparent difference between control and exercised fish than actually existed.

LIVER GLYCOGEN. The average liver glycogen level in control chinook was 0.69% wet weight (Table III). Male chinook had a significantly higher ($0.025 > P > 0.01$) average level ($0.99 \pm 0.171\%$) than female chinook ($0.42 \pm 0.065\%$). The average level in sockeye salmon was 0.61%. The mean level was again significantly higher ($P < 0.001$) in males ($1.03 \pm 0.147\%$) than in females ($0.31 \pm 0.070\%$). In steelhead trout, the average level of liver glycogen was 1.31%. The difference between male ($2.19 \pm 0.502\%$) and female ($0.97 \pm 0.129\%$) steelhead was not significant.

Since liver glycogen does not appear to respond immediately to muscular exertion (Black *et al.*, 1960, 1962), it is possible to make comparisons with other data with some degree of confidence. As noted by Fontaine and Hatey (1953), the levels of glycogen in both muscle and liver in migrating, non-feeding Atlantic salmon represent an equilibrium between forces tending to mobilize carbohydrate and the demands made upon stored glycogen. The present values for liver glycogen are markedly lower than values obtained in 1958 at Bonneville. Collins and Elling (1958, unpublished data) found the following levels of liver glycogen in control fish under conditions similar to those prevailing in the present experiments: chinook, $1.26 \pm 0.281\%$; sockeye, $2.37 \pm 0.299\%$; steelhead, $2.01 \pm 0.348\%$. The 1959 data reported here are also lower than those recorded by Fontaine and Hatey (1953) for migrating adult Atlantic salmon. No explanation is available for the low levels of liver glycogen found in these experiments. However, Black *et al.* (1960, 1962) found marked variations in the average level of liver glycogen in hatchery reared, juvenile trout in the unexercised condition in different years which they attributed, at least in part, to a difference in diet. The higher levels in male than in female salmon noted here were also observed by Fontaine and Hatey (1953), and by Chang and Idler (1960) in migrating sockeye on the Fraser river. The liver glycogen level in the 1959 steelhead trout was nearly twice as high as in either of the salmon species.

The liver glycogen levels of terminated and volitional fish in the experimental fishways did not differ significantly from each other or from the control levels. This finding is in accordance with earlier reports by Black *et al.* (1960, 1962) on rainbow trout. Liver glycogen levels in salmonid fishes do not appear to be affected by muscular activity, at least on a short-term basis. However, a high

degree of variation between individual levels seems to be characteristic, and may be sufficient to mask slight changes in response to exercise. Liver glycogen levels are recorded in the tables for all conditions, but will not be discussed.

COMPARISON OF MALE AND FEMALE FISH

Except for higher liver glycogen levels in male than in female salmon, no sex-related differences in lactate and glycogen levels or in performance were observed in either control or 104-pool terminated fish. In the long-run and volitional groups, there were not enough fish to permit a comparison between males and females. Collins *et al.* (1963) observed a higher blood lactate level in female than in male chinook following ascent of the fishways, but this was not confirmed in the present study.

104-POLY TERMINATED FISH

CHINOOK. Average blood lactate level in chinook salmon sampled immediately upon entering the 104th pool (i.e. 104 ft or 31.7 m ascent) in the 1:16 slope fishway was 29.4 mg% (Table IV) as compared with 17.8 mg% in control chinook (Table III). In chinook sampled after 104 pools in the 1:8 fishway the average was 32.4 mg%. The $1\frac{1}{2}$ - to 2-fold increase over the control level was significant in both fishways ($P < 0.001$) and is typical of fish travelling at a cruising rate involving moderate exercise (Black, 1957a; Black *et al.*, 1960, 1962). The difference between the blood lactate levels in the 1:16 and 1:8 fishways was not significant.

Muscle glycogen levels for 104-pool terminated chinook averaged 0.135% in the 1:16 fishway and 0.092% in the 1:8 fishway (Table IV) as compared with 0.127% in control fish (Table III). The level in the 1:16 fishway does not differ significantly from the control level, however, the level in the 1:8 fishway is significantly lower than both the control ($0.01 > P > 0.005$) and the 1:16 ($P < 0.001$) levels. The relative ease of sampling fish from the 104th pool (i.e. the upper turn pool on the 7th circuit) and the possibility that fish struggle less after exercise than in the control state may account for the fact that level of muscle glycogen in 104-pool terminated chinook in the 1:16 fishway appears higher than the control level, and may mean that the actual reduction in the 1:8 fishway was somewhat greater than indicated. Black *et al.* (1962) have shown that 2 min of strenuous exercise may result in a 50% reduction in muscle glycogen level. Since there was no difference in sampling 104-pool fish from the two fishways, the significant lowering of muscle glycogen after 104 pools in the 1:8 fishway compared with the 1:16 fishway is apparently real and probably related to the greater degree of exercise in the steeper fishway.

The mean time taken for ascent of 104 pools in the 1:16 fishway was 207 min, and in the 1:8 fishway was 227 min (Table V). This difference, while not significant, may have been due to the creation of blind pockets on the downstream weir faces by the installation of vertical stabilizers in the 1:8 fishway (Fig. 3 and 4). In the previous season's work (Collins *et al.*, 1963) when the vertical stabilizers were not used (condition 2C, Fig. 2) the mean passage time of chinook in the 1:8 fishway (151 ± 9.6 min) was actually slightly less than the

TABLE IV. Body weights, blood and muscle lactate levels, and muscle and liver glycogen levels in migrating Columbia river chinook salmon (*O. tshawytscha*) at the completion of ascents of 104 pools (104 ft) in the experimental fishways, Bonneville, 1959.

	Body weight	Lactate		Glycogen	
		Blood	Muscle	Muscle	Liver
1:16-slope	Mean $\pm$ SE		mg/100 g	%	%
	No. of fish	29.4 $\pm$ 1.54	384 $\pm$ 16.3	0.135 $\pm$ 0.0094	0.78 $\pm$ 0.164
	Range	32	33	33	33
		13.7-51.4	192-561	0.053-0.304	0.07-4.96
	Male mean (<i>n</i>)	32.3 (12)	442 (12)	0.127 (12)	1.35 (12)
1:8-slope	Female mean (<i>n</i>)	27.7 (21)	351 (21)	0.139 (21)	0.45 (21)
	Mean $\pm$ SE	32.4 $\pm$ 1.92	403 $\pm$ 16.5	0.092 $\pm$ 0.0069	0.55 $\pm$ 0.096
	No. of fish	34	34	34	34
	Range	15.9-59.6	225-597	0.022-0.188	0.04-2.78
	Male mean (<i>n</i>)	30.1 (14)	397 (14)	0.094 (14)	0.94 (14)
	Female mean (<i>n</i>)	34.1 (20)	408 (20)	0.091 (20)	0.27 (20)

TABLE V. Mean passage times (in *minutes*) of migrating Columbia river chinook salmon (*O. tshawytscha*), sockeye salmon (*O. nerka*) and steelhead trout (*S. gairdneri*) which completed 104 pools (104 ft) in the experimental fishways. Bonneville, 1959.

	Chinook		Sockeye		Steelhead	
	1:16	1:8	1:16	1:8	1:16	1:8
Mean time 104 pools	209	227	141	181	136	158
± SE	±8.3	±7.1	±6.1	±7.1	±6.3	±4.7
No. of fish	84	84	26	26	49	49
Range	104-526	121-456	82-210	137-262	83-331	103-276
Mean time per pool	2.01	2.18	1.36	1.74	1.31	1.52

in the 1:16 fishway (160 ± 15.9 min). The latter data apply to fall-run fish only, while the former represent an average of all runs (spring to fall). It is impossible to state what effect the delay may have had on the biochemistry of fish in the 1:8 fishway, since there is not sufficient data for any single group of fish under the same conditions (i.e. alternating weir crests) in 1958 to compare with the present data.

SOCKEYE. Average blood lactate values in sockeye salmon after 104 pools were 31.2 mg% in the 1:16 fishway, and 42.4 mg% in the 1:8 fishway (Table VI) as compared with a control level of 17.4 mg% (Table III). The increase over the control value was significant for both fishways ($P < 0.001$), and the 1:8 level was significantly higher than the 1:16 level ($0.01 > P > 0.005$). As in the case of the chinook, the increase in lactate is of the order found in young trout during moderate sustained exercise. A significant difference between the 1:16 and 1:8 blood lactate levels was found only in sockeye salmon, and was not apparent in the previous year's experiments (Collins *et al.*, 1963).

Muscle glycogen levels of sockeye after 104 pools in the 1:16 fishway averaged 0.074% (Table VI). This value was not significantly different from the control level of 0.086% (Table III). In the 1:8 fishway the average muscle glycogen level for 104-pool terminated sockeye was 0.053% which was significantly lower than both the control ($P < 0.001$) and the 1:16-slope ($0.005 > P > 0.001$) values. The greater reduction of muscle glycogen in the steeper fishway is concordant with the greater degree of activity reflected in the blood lactate increase above. The situation is similar to that seen in chinook salmon, but is more pronounced in the sockeye.

There were no significant differences in lactate or glycogen levels of fresh as compared with heldover sockeye. The effects of exercise in both fishways were evidently sufficient to overcome the reduction in blood lactate seen in control sockeye when they were held overnight.

Mean passage time for sockeye ascending 104 pools in the 1:8 fishway was 181 min, a value which was significantly longer ($P < 0.001$) than the mean time of 141 min in the 1:16 fishway. No data are available from the 1958 experiments

TABLE VI. Body weights, blood and muscle lactate levels, and muscle and liver glycogen levels in migrating Columbia river sockeye salmon (*O. nerka*) at the completion of ascents of 104 pools (104 ft) in the experimental fishways, Bonneville, 1959.

	Body weight	Lactate		Glycogen	
		Blood	Muscle	Muscle	Liver
1:16-slope	Mean $\pm$ SE				
	No. of fish	mg%	mg/100 g	%	%
	Range				
Fresh (held 1-6 hr) mean (<i>n</i>)	1.31 $\pm$ 0.037	31.2 $\pm$ 1.91	396 $\pm$ 19.6	0.074 $\pm$ 0.0041	0.89 $\pm$ 0.119
	18	18	18	18	18
	1.02-1.58	20.7-54.6	235-583	0.043-0.110	0.15-1.76
Held overnight mean (<i>n</i>)	1.40 (8)	31.8 (8)	383 (8)	0.076 (8)	1.29 (8)
	Female mean (<i>n</i>)	30.8 (10)	407 (10)	0.072 (10)	0.57 (10)
	1.24 (10)				
Fresh (held 1-6 hr) mean (<i>n</i>)	1.34 (10)	31.1 (10)	393 (10)	0.080 (10)	0.77 (10)
	1.25 (6)	32.5 (6)	396 (6)	0.066 (6)	1.04 (6)
1:8-slope	Mean $\pm$ SE	42.4 $\pm$ 3.17	382 $\pm$ 15.5	0.053 $\pm$ 0.0048	0.75 $\pm$ 0.169
	No. of fish	18	18	18	18
	Range	17.6-63.2	282-522	0.032-0.112	0.06-2.51
Fresh (held 1-6 hr) mean (<i>n</i>)	1.42 (10)	40.8 (10)	370 (10)	0.058 (10)	1.15 (10)
	Female mean (<i>n</i>)	42.3 (8)	398 (8)	0.046 (8)	0.25 (8)
	1.29 (8)				
Held overnight mean (<i>n</i>)	1.40 (12)	43.0 (12)	391 (12)	0.051 (12)	0.70 (12)
	1.26 (5)	43.4 (5)	357 (5)	0.055 (5)	1.00 (5)

TABLE VII. Body weights, blood and muscle lactate levels, and muscle and liver glycogen levels in migrating Columbia river steelhead trout (*S. gairdneri*) at the completion of ascents of 104 pools (104 ft) in the experimental fishways, Bonneville, 1959.

	Body weight	Lactate		Glycogen	
		Blood	Muscle	Muscle	Liver
1:16-slope	kg	mg%	mg/100 g	%	%
	Mean $\pm$ SE	20.0 $\pm$ 1.05	424 $\pm$ 14.4	0.070 $\pm$ 0.0041	1.16 $\pm$ 0.114
	No. of fish	37	38	38	38
	Range	5.8-23.8	261-607	0.025-0.132	0.22-3.03
	Male mean (<i>n</i>)	22.2 (13)	453 (14)	0.064 (14)	1.33 (14)
1:8-slope	Female mean (<i>n</i>)	18.9 (24)	407 (24)	0.074 (24)	1.07 (24)
	Mean $\pm$ SE	20.5 $\pm$ 1.17	395 $\pm$ 14.7	0.065 $\pm$ 0.0037	1.14 $\pm$ 0.137
	No. of fish	36	36	36	36
	Range	8.2-36.5	232-623	0.026-0.121	0.27-2.87
	Male mean (<i>n</i>)	18.5 (13)	370 (13)	0.067 (13)	1.13 (13)
1:8-slope	Female mean (<i>n</i>)	21.6 (23)	410 (23)	0.065 (23)	1.15 (23)

for sockeye passage times or biochemistry in the 1:8 fishway with alternating weir crests without vertical stabilizers. As in the case of the chinook above, it is possible that the modification in design caused a delay in the 1:8 fishway.

STEELHEAD. Average blood lactate levels in 104-pool terminated steelhead trout were 20.0 mg% in the 1:16 fishway and 20.5 mg% in the 1:8 fishway (Table VII). These values both represent significant increases ($P < 0.001$) over the control level of 12.2 mg% (Table III), but are not significantly different from each other. It should be re-emphasized that all blood lactate increases observed during 104-pool terminated ascents were of the order of magnitude associated with moderate sustained exercise, and did not approach the levels found in trout which have been chased to exhaustion for periods up to 15 min (Black, 1957a, b, c; Black *et al.*, 1959, 1960, 1962).

Average muscle glycogen levels in 104-pool terminated steelhead were 0.070% in the 1:16 fishway and 0.065% in the 1:8 fishway (Table VII). The 1:16 mean level does not differ significantly from the control level of 0.079% (Table III), but the 1:8 level is significantly lower ($0.05 > P > 0.025$) than the control, again indicating the probability of a slightly greater drain on metabolic stores in the steeper fishway. The 1:16 and 1:8 muscle glycogen levels do not differ significantly from each other.

The average passage time for steelhead completing 104 pools in the 1:16 fishway was 136 min which was significantly less ($0.01 > P > 0.005$) than the average time of 158 min in the 1:8 fishway (Table V). The delay may have been due to the use of vertical stabilizers in the steeper fishway. Although the passage times of steelhead and sockeye were similar in the 1:16 fishway, the time taken for steelhead to complete 104 pools in the 1:8 fishway was significantly less ($0.01 > P > 0.005$) than for sockeye. Yet the steelhead did not show any greater lactate increase in the steeper fishway, whereas the sockeye did.

LONG-RUN TERMINATED FISH

CHINOOK. Long-run chinook salmon were terminated at an average of 522 pools (range, 232–1000) in the 1:16 fishway, and 527 pools (range, 248–1000) in the 1:8 fishway. Several of the extremely long ascents were interrupted by the fish stopping volitionally during the night for periods totalling up to $7\frac{1}{2}$ hr. This occurred only in chinook and mainly during the spring-run. Since these fish were in an actively moving state at the time of sampling, they are included in the terminated category.

In the 1:16 fishway, the blood lactate of long-run chinook was elevated to 27.6 mg% (Table VIII). However, presumably because of the high degree of individual variation (S.E. ± 7.30) this value was not significantly different from the control level (Table III), nor did it differ from the level in 104-pool terminated chinook (Table IV). Muscle glycogen in long-run chinook in this fishway averaged 0.145% (Table VIII) and showed no significant change from either the control or 104-pool terminated levels.

In the 1:8 fishway, the average blood lactate level of long-run chinook was 29.6 mg% (Table VIII), a value which is significantly higher ($0.005 > P > 0.001$)

TABLE VIII. Body weights, blood and muscle lactate levels, and muscle and liver glycogen levels in migrating Columbia river chinook salmon (*O. tshawytscha*), sockeye salmon (*O. nerka*) and steelhead trout (*S. gairdneri*) at the completion of long-run terminated ascents (between 105 and 1000 ft) in the experimental fishways. The average numbers of pools completed are given in column 2. Bonneville, 1959.

1	2	3	4		5	6		7
			Body weight			Lactate		
	No. of pools completed	k_2	Blood	Muscle	Muscle	Muscle	Liver	
			mg%	mg/100 g	%	%	%	
Chinook 1:16-slope	Mean $\pm$ SE No. of fish Range	7.56 $\pm$ 1.377 7 522 $\pm$ 108.8 232-1000	27.6 $\pm$ 7.30 7 7.1-67.1	36.4 $\pm$ 11.0 7 223-482	0.145 $\pm$ 0.0463 7 0.023-0.336	0.51 $\pm$ 0.127 7 0.07-1.01		
	Mean $\pm$ SE No. of fish Range	8.50 $\pm$ 0.823 7 4.73-11.38	29.6 $\pm$ 3.07 7 20.4-41.6	37.5 $\pm$ 32.6 7 237-493	0.068 $\pm$ 0.0107 6 0.042-0.101	0.41 $\pm$ 0.091 7 0.07-0.74		
Sockeye 1:16-slope	Mean $\pm$ SE No. of fish Range	1.41 $\pm$ 0.049 4 648-1000	19.7 $\pm$ 6.50 4 7.9-37.5	328 $\pm$ 54.8 4 214-444	0.028 $\pm$ 0.0082 4 0.015-0.052	0.59 $\pm$ 0.280 4 0.22-1.42		
	Mean $\pm$ SE No. of fish Range	1.25 $\pm$ 0.083 4 1.07-1.44	30.6 $\pm$ 3.84 4 21.9-40.5	317 $\pm$ 37.0 4 206-361	0.024 $\pm$ 0.0026 4 0.018-0.026	0.49 $\pm$ 0.194 4 0.09-0.95		
Steelhead 1:16-slope	Mean $\pm$ SE No. of fish Range	2.41 $\pm$ 0.270 7 1.56-3.62	18.6 $\pm$ 4.14 6 8.4-34.7	354 $\pm$ 36.2 7 251-545	0.050 $\pm$ 0.0068 7 0.021-0.074	1.64 $\pm$ 0.348 7 0.45-2.48		
	Mean $\pm$ SE No. of fish Range	2.46 $\pm$ 0.228 6 1.81-3.26	15.0 $\pm$ 2.29 6 5.6-20.6	407 $\pm$ 21.0 6 330-475	0.040 $\pm$ 0.0044 6 0.027-0.059	1.48 $\pm$ 0.366 6 0.54-3.07		

han the average in control chinook, but did not differ significantly from the values for 104-pool terminated fish in the same fishway or long-run fish in the 1:16 fishway. The mean muscle glycogen in long-run chinook in the steeper fishway was 0.068% and represented a significant decrease from the control level ($0.005 > P > 0.001$). Like the blood lactate, the muscle glycogen of long-run fish in the 1:8 fishway was not significantly different from either the 104-pool or the 1:16 long-run levels.

The small size of the long-run sample groups ($n = 7$ in each fishway) probably contributed to the fact that more of the differences recorded were not statistically significant.

Chinook salmon apparently can accomplish extended ascents of up to 1000 pools in either fishway without showing evidence of more than a moderate degree of activity as judged by the blood lactate changes. In the 1:16 fishway muscle glycogen levels are not diminished during either moderate or long ascents. In the 1:8 fishway, the utilization of muscle glycogen is significant with respect to the control value in both 104-pool and long ascents, and although statistically unproven, appears to be progressive. At the end of 104 pools, the average glycogen level of chinook was about $\frac{3}{4}$ of the control value. In long-run fish it had diminished to $\frac{3}{4}$ of the 104-pool level, or $\frac{1}{2}$ the control level.

The average times taken to accomplish each 100-pool section of the prolonged ascents are shown in Fig. 5. A progressive increase in rate of ascent occurred in chinook during the first 300–500 pools of both fishways. Between the 500th and 800th pools, a marked reduction in rate appears which coincides with the volitional interruptions in progress mentioned earlier. This phenomenon of stopping in the fishways is similar to that seen in volitional fish.

SOCKEYE. Sockeye salmon ascended an average of 839 pools (range, 648–1000) before termination in the 1:16 fishway, and 772 pools (range, 536–1000) in the 1:8 fishway. In both fishways the ascents were considerably longer than those of chinook salmon.

The average blood lactate level of long-run sockeye in the 1:16 fishway was 19.7 mg% (Table VIII). This value was not significantly different from the control level (Table III) and was significantly lower ($0.05 > P > 0.025$) than the level for 104-pool terminated sockeye in the same fishway (Table VI). The average blood lactate of long-run sockeye in the 1:8 fishway was 30.6 mg% which represents a significant increase ($0.01 > P > 0.005$) over the control level. In the steeper fishway the blood lactate level of long-run fish was again lower than that of 104-pool terminated fish, but the difference was not significant. The difference in blood lactates of long-run sockeye between the fishways was not significant, probably because of the small size of the sample groups.

The average muscle glycogen level of 0.028% in the 1:16 fishway (Table VIII) was significantly lower ($P < 0.001$) than both the control level (Table III) and the level in 104-pool terminated sockeye in the same fishway (Table VI). The average muscle glycogen level for long-run sockeye in the 1:8 fishway (0.024%) was slightly, but not significantly lower than the 1:16 level. It was, however,

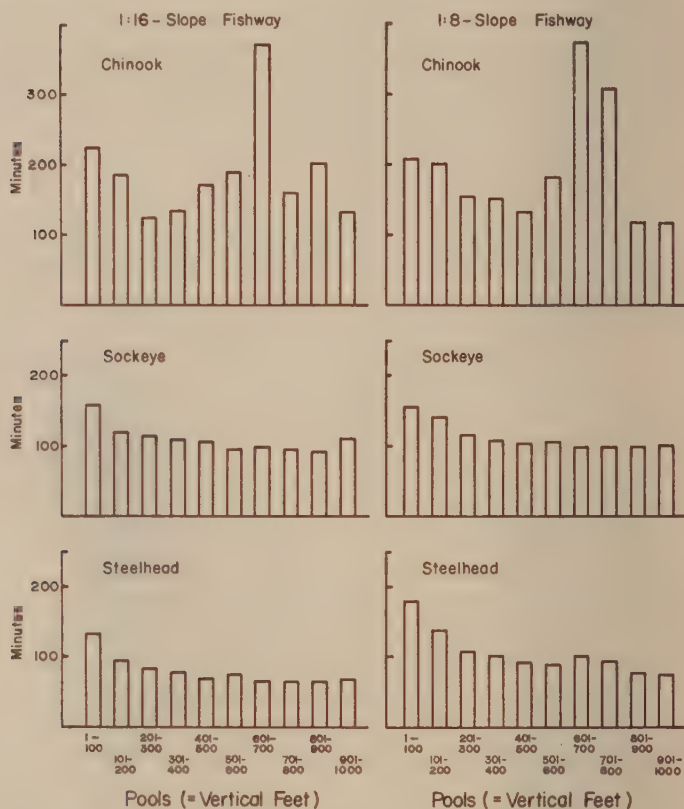


FIG. 5. Average ascent times in minutes per 100 pools for long-run terminated chinook salmon (*Oncorhynchus tshawytscha*), sockeye salmon (*O. nerka*) and steelhead trout (*Salmo gairdneri*) in the 1:16- and 1:8-slope experimental "endless" fishways. Bonneville, 1959.

significantly below both the control level ($P < 0.001$) and the 104-pool terminated level ($0.005 > P > 0.001$) in that fishway.

In sockeye salmon, muscle glycogen is apparently utilized during long ascent of either fishway, in contrast to chinook in which utilization was observed only in the 1:8 fishway. Evidence of a progressive decrease in muscle glycogen stores related to the total number of pools ascended, is more definite in sockeye salmon in both fishways than in the chinook in the 1:8 fishway. Of great interest is the reduction in blood lactate levels which appears in sockeye when the ascent is prolonged beyond the 104th pool. This reduction may possibly be related to the increased rate of ascent observed during the first 400-500 pools (Fig. 5) and may indicate some form of "learning" or adaptation in the experimental situation. None of the long-run sockeye stopped moving during the later stage as did the chinook.

STEELHEAD. The long-run steelhead trout were terminated at an average number of pools intermediate between the chinook and sockeye salmon. As shown in Table VIII, the average number of pools completed in the 1:16 fishway (mean, 719; range, 344–1000) was somewhat greater than the number in the 1:8 fishway (mean, 616; range, 216–1000).

The slight increases in mean blood lactate levels of long-run steelhead (Table VIII) in both fishways were not significant when compared with the control fish (Table III). Nor was the difference between the blood lactate level of 104-pool terminated steelhead (Table VII) and that of long-run fish in the 1:16 fishway. In the 1:8 fishway however the average blood lactate value of 15.0 mg% in the long-run steelhead was significantly lower than the average of 20.5 mg% in the 104-pool terminated fish ($0.05 > P > 0.025$). There was no significant difference in blood lactate levels of long-run steelhead between the 1:16 and 1:8 fishways.

The average muscle glycogen level in long-run steelhead in the 1:16 fishway was 0.050% (Table VIII) which value was significantly lower ($0.025 > P > 0.01$) than the control level of 0.079% (Table III). Muscle glycogen in long-run steelhead in the 1:8 fishway (0.040%) was also significantly lower than the control level ($P < 0.001$) and the level of 0.065% (Table VII) in 104-pool terminated steelhead ($0.01 > P > 0.005$) in the same fishway. The difference in muscle glycogen levels between the two fishways was not significant for long-run steelhead.

Steelhead appear to be more like sockeye than chinook in their response to prolonged ascents. The moderate accumulation of lactate seen during the early stages (i.e. the first 104 pools) is reduced in long-run fish especially in the 1:8 fishway. Muscle glycogen is utilized during long ascents in both fishways, although no significant reduction had been observed after 104 pools in the 1:16 fishway. In the steeper fishway, the breakdown of muscle glycogen is definitely progressive as was the case with sockeye. Steelhead also showed a consistent increase in rate of ascent during the first 400–500 pools in both fishways (Fig. 5) and showed no tendency to stop moving as did the chinook.

1000-POOL TERMINATED FISH

Lactate and glycogen levels of individual fish of all three species which were terminated after 1000 pools in both fishways are given in Table IX, together with body weights, sex, total duration of the ascent, and total duration of inactive periods which exceeded 60 min in those chinook which stopped. These data were included in the averages for long-run terminated fish discussed above, but are presented separately here in order to give some indication of the biochemical status of fish which have completed a prolonged ascent of a uniform specified length. The number of fish in any given group was not sufficient to permit comparison of mean lactate and glycogen levels. The individual blood lactate and muscle glycogen levels appear to follow the patterns discussed above for the mean levels in long-run terminated fish. The performance data and blood lactate levels of these fish have been discussed fully by Collins *et al.* (1962).

TABLE IX. Body weights, sex, blood and muscle lactate levels, and muscle and liver glycogen levels of individual migrating Columbia river chinook salmon (*O. tshawytscha*), sockeye salmon (*O. nerka*) and steelhead trout (*S. gairdneri*) at the completion of ascents of 1000 pools (1000 ft) in the experimental fishways. The times taken to complete 1000 pools are given in column 4. The number (column 5) and the total length (column 6) of inactive periods which exceeded 60 min are presented. Bonneville, 1959.

	1 Fishway slope	2 Body weight kg	3 Sex	4 Duration of ascent hr:min	5 Number of stops	6 Total length of inactive periods hr:min	7 Lactate		9 Glycogen		10
							Blood mg%	Muscle mg/100 g	Muscle %	Liver %	
Chinook	1:16	9.65	F	28:46	1	1:29	30.3	477	0.291	1.01	
	1:8	9.88	F	31:26	2	5:59	28.7	380	0.101	0.57	
	1:8	10.19	F	31:17	2	7:39	26.6	407	0.042	0.23	
Sockeye	1:16	1.44	F	15:24	0	0	20.7	397	0.022	0.40	
	1:16	1.33	M	22:01	0	0	7.9	257	0.015	0.31	
	1:8	1.44 1.16	M F	20:11 17:18	0 0	0 0	21.9 28.9	350 206	0.026 0.022	0.66 0.09	
Steelhead	1:16	1.78	M	11:34	0	0	8.4	324	0.074	1.63	
	1:16	2.27	M	9:19	0	0	19.7	387	0.021	0.45	
	1:16	3.05	F	12:37	0	0	9.8	368	0.057	0.46	
	1:8	1.81	F	15:22	0	0	13.4	441	0.059	0.85	

TABLE X. Body weights, blood and muscle lactate levels, and muscle and liver glycogen levels in migrating Columbia river chinook salmon (*O. tshawytscha*), sockeye salmon (*O. nerka*) and steelhead trout (*S. gairdneri*) sampled at the end of a 60-min volitional stop during ascent of the experimental fishways. The average numbers of pools completed before stopping are given in column 2. Bonneville, 1959.

1	2	3	4		5		6		7
			Body weight		Lactate		Glycogen		
	No. of pools completed		Blood	Muscle	Muscle	Liver			
		kg	mg%	mg/100 g	%	%			
Chinook 1:16-slope	Mean $\pm$ SE No. of fish Range	8.54 $\pm$ 1.113 10 3-242	20.8 $\pm$ 3.42 10	439 $\pm$ 35.4 10	0.111 $\pm$ 0.0217 10	0.66 $\pm$ 0.197 10			
		2.60-12.71	5.4-40.8	260-590	0.045-0.243	0.23-1.94			
1:8-slope	Mean $\pm$ SE No. of fish Range	5.66 $\pm$ 1.126 11	20.1 $\pm$ 3.54 11	434 $\pm$ 29.4 11	0.097 $\pm$ 0.0127 11	0.54 $\pm$ 0.175 11			
		1.78-12.14	8.7-48.1	242-562	0.042-0.203	0.10-2.18			
Sockeye 1:16-slope	Mean $\pm$ SE No. of fish Range	1.42 $\pm$ 0.063 8	10.3 $\pm$ 1.44 8	408 $\pm$ 42.7 8	0.064 $\pm$ 0.0110 8	1.05 $\pm$ 0.363 8			
		1.19-1.70	5.2-16.9	224-583	0.028-0.132	0.18-3.37			
1:8-slope	Mean $\pm$ SE No. of fish Range	1.46 $\pm$ 0.097 8	15.3 $\pm$ 3.48 8	361 $\pm$ 20.8 8	0.053 $\pm$ 0.0086 8	0.83 $\pm$ 0.188 8			
		1.21-2.09	5.5-34.0	268-441	0.019-0.088	0.01-1.61			
Steelhead 1:16-slope	Mean $\pm$ SE No. of fish Range	2.21 $\pm$ 0.102 10	12.9 $\pm$ 3.25 10	454 $\pm$ 29.8 10	0.047 $\pm$ 0.0057 9	1.00 $\pm$ 0.285 9			
		1.81-2.60	4.1-39.0	261-576	0.015-0.075	0.23-2.83			
1:8-slope	Mean $\pm$ SE No. of fish Range	3.28 $\pm$ 0.421 10	10.7 $\pm$ 1.56 10	407 $\pm$ 13.8 10	0.063 $\pm$ 0.0117 10	1.21 $\pm$ 0.129 10			
		1.70-5.55	3.6-20.6	357-513	0.012-0.141	0.74-1.87			

TABLE XI. Body weights, blood and muscle lactate levels, and muscle and liver glycogen levels in individual migrating Columbia river chinook salmon (*O. tshawytscha*) and sockeye salmon (*O. nerka*) sampled after a 30-min volitional stop, and in individual chinook salmon and steelhead trout (*S. gairdneri*) which stopped for 60 min in the 1st pool during ascents of the experimental fishways. Bonneville, 1959.

Species	Fishway slope	Condition		Body weight kg	Lactate		Glycogen	
		Duration of stop min	No. of pools completed		Blood mg%	Muscle mg/100 g	Muscle %	Liver %
Chinook	1:16	30	47	6.43	21.6	405	0.155	0.25
	1:16	30	18	9.03	49.7	412	0.031	0.30
	1:16	30	22	14.72	50.0	315	0.107	1.06
	1:16	30	214	6.45	27.7	554	0.170	0.29
	1:8	30	97	3.71	15.7	384	0.105	1.01
Sockeye	1:8	30	17	7.93	75.4	513	0.091	1.17
	1:16	30	93	1.19	34.6	417	0.027	0.36
	1:8	30	43	1.42	18.1	314	0.080	0.31
Chinook	1:16	60	1	1.61	15.8	359	0.081	0.30
	1:16	60	1	3.62	10.4	353	0.044	0.33
	1:16	60	1	5.07	18.1	455	0.111	0.06
Steelhead	1:16	60	1	3.82	9.8	331	0.077	2.06
	1:16	60	1	1.81	21.0	372	0.072	0.64

VOLITIONAL-STOP FISH

CHINOOK. The chinook salmon which were sampled after they had stopped or 60 min in one pool during ascent of the experimental fishways (Table X) had completed an average of 65 pools (range, 3–242) in the 1:16 fishway and 189 pools (range, 4–964) in the 1:8 fishway. The large difference is due to the fact that two fish in the 1:8 fishway had ascended 529 and 964 pools, respectively, before sampling, as compared with the maximum ascent of 242 pools in the 1:16 fishway. When these two fish are eliminated, the average number of pools completed in the 1:8 fishway becomes 63 (range, 4–121). However, when the individual lactate and glycogen levels for these two fish were considered, they were found to be within the range of all volitional chinook in the 1:8 fishway, therefore they are included with this group.

A small group of fish which did not proceed beyond the first pool in the 1:16 fishway within 60 min is considered to be a special case and is presented in Table XI. Salmon which were sampled after stopping for 30 min in one pool are also considered separately.

The percentage of chinook salmon which stopped volitionally before reaching the 104th pool was 23.6% in the 1:16 fishway and 21.5% in the 1:8 fishway (Table XII). These figures do not include volitional stops of 30 min, nor volitional stops after ascents longer than 104 pools.

TABLE XII. Percentage of migrating Columbia river chinook salmon (*O. tshawytscha*), sockeye salmon (*O. nerka*) and steelhead trout (*S. gairdneri*) which completed 104 pool (104 ft) ascents of the experimental fishways without stopping volitionally for 60 min. These figures do not include fish which were sampled after a 30-min volitional stop. Bonneville, 1959.

	1:16-slope			1:8-slope		
	Chinook	Sockeye	Steelhead	Chinook	Sockeye	Steelhead
No. of fish completing 104 pools	84	26	49	84	26	49
No. of volitional stops	26	4	9	23	4	6
Total no. of fish	110	30	58	107	30	55
Percentage completing 104 pools	76.4	86.7	84.5	78.5	86.7	89.1
Percentage stopping volitionally	23.6	13.3	15.5	21.5	13.3	10.9

The blood lactate levels in volitional chinook of 20.8 mg% for the 1:16 fishway and 20.1 mg% for the 1:8 fishway (Table X) were not significantly higher than the control value of 17.8 mg% (Table III) nor were they significantly different from each other. They were however significantly lower than the levels in 104-pool terminated chinook (Table IV) in both the 1:16 fishway ($0.025 > P > 0.01$) and the 1:8 fishway ($0.005 > P > 0.001$).

Muscle glycogen levels in volitional chinook were 0.111% in the 1:16 fishway and 0.097% in the 1:8 fishway (Table X). These values are slightly lower than the control level of 0.127% (Table III), but the differences are not significant. Nor were there any significant differences between muscle glycogen levels in volitional chinook and those in 104-pool terminated fish in the corresponding fishways (Table IV). The difference between muscle glycogen levels of volitional chinook in the two fishways was not significant.

Although the blood lactate levels of volitional chinook are significantly lower than the 104-pool terminated levels, the true degree of recovery during the 60 min they remained in one pool cannot be estimated, since the actual lactate levels at the time of stopping are not known. However some degree of recovery seems probable. Similarly, the extent of muscle glycogen recovery is unknown, but appears to be slight.

It should be noted that although these volitional fish stopped moving up the fishways, they were not completely inactive during the 60-min period. They maintained their position against the flow of water, and swam about the pool. Chinook salmon which had been exhausted by extremely rapid ascents in one of the unsuccessful design modifications of the 1:8 fishway in 1958 were studied by Collins *et al.* (1963). These fish were obviously fatigued, drifted back down the fishway to the lowermost pool and showed an average blood lactate of 123 mg%. The volitional fish under consideration in the present paper showed none of these signs of fatigue. It is most probable that unassessed factors such as sexual maturity, water temperature and different behavioural patterns are involved in this tendency to stop moving. In the case of chinook salmon, volitional stops were observed mainly in the spring-run. In fact a tendency to balkiness was characteristic of these fish in both the experimental and the regular fishways at Bonneville dam. Tests in 1958 (Collins *et al.*, 1963) indicated that approximately 40% of the spring chinooks stopped for 60 min or more in a fishway pool. By contrast, virtually all of the fall-run passed through the fishway without making a 60-min stop.

SOCKEYE. The average number of pools ascended by volitional sockeye salmon (Table X) before stopping was 263 pools (range, 35-632) in the 1:16 fishway and 232 (range, 46-577) in the 1:8 fishway. Half of the volitional sockeye in each fishway were from the long-run group (i.e. had ascended more than 104 pools). The percentage of sockeye which stopped of their own volition for 60 min before reaching the 104th pool was 13.3% in both fishways (Table XII).

Average blood lactate level of volitional sockeye in the 1:16 fishway (10.3 mg%, Table X) was significantly lower ($0.01 > P > 0.005$) than the control level of 17.4 mg% (Table III). It was also significantly lower ($P < 0.001$) than the level in 104-pool terminated sockeye in the same fishway (31.2 mg%, Table VI). The blood lactate level of volitional sockeye in the 1:8 fishway was 15.3 mg% (Table X) which is very close to the control level and significantly lower ($P < 0.001$) than the level in 104-pool terminated sockeye in the 1:8 fishway. The difference between the blood lactate levels of volitional sockeye in the 1:16 and 1:8 fishways was not significant.

The average muscle glycogen level in volitional sockeye salmon in the 1:16 fishway was 0.064% (Table X), a value which is lower than both the control level of 0.086% (Table III) and the 104-pool terminated level of 0.074% (Table I). The differences however were not significant. In the 1:8 fishway, the muscle glycogen level of volitional sockeye averaged 0.053% (Table X) which is identical with the level in 104-pool terminated sockeye in the same fishway (Table VI), and significantly lower than the control level ($0.01 > P > 0.005$). There was no significant difference between the muscle glycogen levels of volitional sockeye in the 1:16 and 1:8 fishways.

The very low blood lactate level in volitional sockeye in the 1:16 fishway is similar to that observed in control sockeye which had been held overnight (Table II). Probably this level more nearly represents the true unexercised state than the average of 17.4 mg% recorded for all sockeye controls. Evidently sockeye either were less active or experienced less stress when isolated in one pool of the 1:16 fishway than when kept in the holding pool for 1–6 hr. Although, as in the case of chinook salmon, the true extent of recovery as judged by the blood lactate level is not known, it appears to be quite marked in sockeye within 60 min of the cessation of exercise in both fishways. Muscle glycogen values in volitional sockeye showed no real evidence of recovery from levels for actively ascending fish during the 60-min stop.

STEELHEAD. The average number of pools completed by volitional steelhead trout in the 1:16 fishway was 244 (range, 26–985), with four out of ten fish in the long-run category. In the 1:8 fishway, the average was 229 pools (range, 9–679) with one-half of the fish from the long-run group.

In the 1:16 fishway, 15.5% of the steelhead stopped of their own volition before reaching the 104th pool. In the 1:8 fishway the percentage was 10.9% (Table XII)

Average blood lactate levels of volitional steelhead were 12.9 mg% in the 1:16 fishway and 10.7 mg% in the 1:8 fishway (Table X). These values were not significantly different, nor did either of them differ significantly from the control level of 12.2 mg% (Table III). The blood lactate level of volitional steelhead in the 1:16 fishway did not differ significantly from the level for 104-pool terminated fish in the same fishway (Table VII). The level in volitional steelhead in the 1:8 fishway was however significantly lower ($P < 0.001$) than the level for 104-pool terminated fish.

In the 1:16 fishway, the average muscle glycogen level was 0.047% (Table X) which was significantly lower than both the control level of 0.079% ($0.005 > P > 0.001$), and the 104-pool terminated level of 0.070% ($0.025 > P > 0.01$). In the 1:8 fishway, the average muscle glycogen level of volitional steelhead was 0.063% (Table X) which was similar to the 104-pool terminated level (Table VII), but not significantly different from either the control (Table III) or the 1:16 volitional levels.

The volitional steelhead, like the chinook and sockeye, gave some indication of recovery during the 60 min stop on the basis of lowered lactate levels, although

the extent to which this represents true recovery is not known. Muscle glycogen levels did not appear to be restored to the control level during this time.

Steelhead, like the spring-run chinook discussed earlier, have been known to linger in fishways for lengthy periods during certain times of the year. Each winter during draining of the fishways at Bonneville for repair purposes, large numbers of steelhead are found in the pools. Since only a token migration of steelhead passes the Bonneville dam during winter, the fish found in the fishways are presumably previous summer and fall migrants that have taken up residence in the pools. These apparently stay in the fishway for several months before moving upstream in the spring for spawning. It is quite possible that these fish have found the hydraulic conditions in the fishway pools to their liking and are merely spending the time in the process of maturation. It is equally probable that the volitional fish in this study stopped for similar reasons and not because of fatigue.

VOLITIONAL FISH—SPECIAL CONDITIONS

Data for individual fish which were sampled after a 30-min volitional stop and for fish which did not proceed beyond the first pool within 60 min (i.e. 1-pool volitional fish) are presented in Table XI. The data are too few to permit statistical treatment.

The 30-min volitional chinook salmon showed rather high blood lactate levels (1:16 fishway mean, 37.3 mg%; 1:8 mean, 45.6 mg%) as compared with the 60-min volitional (Table X) and control chinook (Table III). These 30-min volitional mean values were, in fact, higher than the corresponding levels in the 104-pool terminated chinook (Table IV), although the ranges of values coincide, for the 1:16 fishway at least. The high blood lactate values after a 30-min stop may be some indication of the degree of recovery taking place in the 60-min volitional chinook. However, the data are not complete nor consistent enough to permit an unequivocal interpretation. The muscle glycogen levels in 30-min volitional chinook do not appear to be markedly depleted. In the 30-min volitional chinook, in the 1:16 fishway only, the liver glycogen levels were quite low (mean, 0.48%). It is also interesting to note that the only obvious biochemical alteration in the chinook which stopped for 60-min in the first pool of the 1:16 fishway was the low liver glycogen level (mean, 0.23%). However, because of the wide range of liver glycogen values in control chinook (0.04–2.62% Table III), it is not possible to attach any real significance to these findings.

DISCUSSION

The results of the 1959 experiments at Bonneville are, in general, similar to those reported by Collins *et al.* (1963) for the previous year's work. However the additional data collected in 1959, in particular the muscle glycogen values make clear several aspects of fishway passage which were not obvious from the earlier studies.

Fish of all three species tested (chinook and sockeye salmon and steelhead trout) appeared equally willing to enter, and capable of ascending, either the 1:16- or the steeper 1:8-slope fishway under favourable hydraulic conditions.

The percentage of fish completing a moderate ascent of 104 ft without stopping or 60 min or more was actually greater in the 1:8 fishway for chinook and steelhead, and was at no time less than 76% of those starting. Although the rate of ascent of all species was less in the steeper fishway, and significantly so for sockeye and steelhead, the slower passage may have been due to the creation of blind pockets on the downstream side of each weir by the installation of vertical stabilizers in the 1:8 fishway. When the ascents were extended beyond 104 ft, the difference in passage times between the fishways was reduced. All fish showed the ability to increase their rates of ascent during the first half of long passages in both fishways. After this initial increase, sockeye and steelhead maintained the faster rate up to 1000 ft. Chinook, particularly the spring-run, occasionally stopped voluntarily in the latter half of long ascents in both fishways. Steelhead showed the fastest passage times in both fishways, closely followed by sockeye, while the larger chinook salmon were slowest.

The biochemical data, especially blood lactate and muscle glycogen levels, indicate that the degree of effort involved even in prolonged ascents of either fishway was of the order of magnitude associated with moderate sustained exercise. Muscle lactate values were consistently high in both control and experimental fish, probably because of struggling and delay in sampling. No significant changes in muscle lactate levels were observed in response to exercise in either fishway. The liver glycogen levels in these experiments did not appear to be related to the amount of muscular exercise performed. This lack of change in liver glycogen levels may have been due to the high degree of individual variation between samples. However, it is more likely that the amounts of work performed by these fish were not sufficient to influence the liver glycogen levels.

The blood lactate levels indicate that the greatest degree of anaerobic metabolism occurs during the first approximately 100 ft of ascent in both fishways. All species exhibited a significant $1\frac{1}{2}$ - to $2\frac{1}{2}$ -fold increase in blood lactate over the rather high control levels during ascent of the first 104 pools of either fishway. Presumably this may have been due either to the stress of a new environment, together with a possible delay in readjustment of circulation and respiration and/or to an increased rate of turnover of glycogen. The magnitude of the lactate increase is very similar to that observed in moderately exercised $1\frac{1}{2}$ -year-old rainbow and Kamloops trout (Black, 1957a; Black *et al.*, 1960, 1962), and in no way approaches the large increases found by these and other workers (Secondat and Diaz, 1942; Nakatani, 1957; Black 1957b,c; Leivestad *et al.*, 1957; Parker and Black, 1959; Parker *et al.*, 1959; Tomlinson *et al.*, 1961; Barrett and Connor, 1962; Heath and Pritchard, 1962) in fishes following severe exercise or handling procedures. Only the sockeye salmon in the present study showed a significantly higher blood lactate level after 104 pools in the 1:8 than in the 1:16 fishway.

During ascent of the first 104 pools of the 1:16 fishway, the muscle glycogen levels of all species tested were not significantly decreased below the control levels. Evidently, the utilization of muscle glycogen is so slight at this level of

exercise that the rate of replacement is not exceeded. It is possible that energy for this mild form of exercise could be supplied from direct metabolism of protein and/or fat (Greene, 1921; Pentegoff *et al.*, 1928; Fontaine and Hatey, 1953; Idler and Clemens, 1959; Blažka, 1962, personal communication) or other carbohydrate substrates (Tarr and Leroux, 1962), in which case it seems that a moderately long ascent of the 1:16 fishway does not exceed the energy-producing capabilities of these alternate metabolic pathways. In the 1:8 fishway, however, the muscle glycogen levels of all species after an ascent of 104 pools were significantly below the control levels. The reduction ranged from 18–38% of the control value. In chinook and sockeye salmon, the muscle glycogen levels following 104-pool ascents in the 1:8 fishway were significantly lower than following similar ascents in the 1:16 fishway. It appears that an ascent of moderate height (104 ft) in the steeper 1:8 fishway cannot be accomplished without the utilization of muscle glycogen. The decreases in muscle glycogen, like the increases in blood lactate were not nearly as great as those found following 15 min strenuous exercise in immature trout (Black *et al.*, 1960, 1962).

When the ascents were prolonged up to 1000 pools, the blood lactate levels tended to be lower than those found after 104-pool ascents, especially in sockeye and steelhead. It is probable that lactate is disposed of by excretion and/or by conversion to pyruvate with eventual oxidation. An improvement in circulation at later stages of prolonged ascents would provide more efficient operation of the excretory organs and more adequate tissue oxygenation. It is also possible that the reduction in lactate levels resulted from a lessening of initial stress or a "learning" process, such as that noted by McLeod and Nemenyi (1941) for trout in experimental fishways, which would enable the fish to negotiate the overfalls with less muscular effort. The increasing rate of ascent seen during the first 400–500 pools in long-run fish may be interpreted either as evidence of "learning" or as a result of improved circulatory function.

Despite the fact that lactate levels were reduced in long-run terminated fish, muscle glycogen levels were significantly lower than the control levels in all long-run fish except chinook salmon in the 1:16 fishway. The reduction in muscle glycogen appeared to be progressive, and to depend on the total amount of work accomplished. The apparently continuous expenditure of muscle glycogen makes it doubtful that the low lactate levels in long-run fish were due to the use of alternate pathways of energy production (fat or protein breakdown) to the exclusion of glycolysis. It is equally unlikely that the low lactate levels resulted from exhaustion of muscle glycogen stores in the long-run fish. The muscle glycogen values upon termination (Table VIII) do not seem to be low enough to limit glycolysis. Levels as low as 0.001% have been recorded in young rainbow trout following 2–9 min of strenuous exercise (Black *et al.*, 1962). These trout showed changes in behaviour which suggested severe fatigue. Such evidence of fatigue was not observed in the long-run fish in the present experiments.

Fish of all three species which stopped moving of their own volition were able to maintain position for 60 min or more in either slope fishway. When these

fish were sampled at the end of 60 min in one pool, the blood lactate levels were similar to, or even lower than, the control levels. Although the true degree of recovery is not known since the levels of lactate and glycogen at the time the fish stopped moving were not measured, it is very likely that some reduction in blood lactate occurred. Despite the 60 min of relative inactivity, muscle glycogen levels of most volitional fish remained indistinguishable from or significantly lower than those in corresponding groups terminated at the end of 104 pools. Although the volitional muscle glycogen levels were not significantly different from the control levels in most cases, it seems probable that little, if any, restoration took place during the 60 min.

From the data obtained, it does not seem likely that the volitional fish stopped moving because of glycolytic fatigue. It is possible that exhaustion of other essential metabolites such as ATP or creatine- PO_4 , or inactivation of any of the enzyme systems involved in intermediary metabolism might be the limiting factor. These factors were not studied in the present experiments. However, subjective observations and data on fish passage collected for both the experimental "endless" fishways and the regular operating fishways at Bonneville dam make it appear more probable that the tendency to stop moving for lengthy periods is a behavioural phenomenon. Such factors as water temperature, state of maturity and favourable hydraulic conditions probably affect the movement of migrating fish. The relationship of these factors to the pattern of movement of volitional fish in the experimental fishways has not been fully investigated.

Since the feasibility of using the steeper 1:8-slope fishway for the passage of salmonid fishes has been demonstrated by the performance records in the experimental "endless" fishways, the problem of immediate practical importance is the effect of ascending such fishways on the ultimate well-being of migrating fish. As has been stated repeatedly, the degree of effort, as judged by analysis of the primary carbohydrate energy cycle, is only moderate in either the 1:8- or the 1:16-slope fishway provided the proper hydraulic conditions are attained. However, there is evidence that moderately long ascents (approximately 100 ft) of the steeper fishway require a small but significant expenditure of muscle glycogen which is not required during a similar ascent in a 1:16-slope fishway. The effect of such reduction in muscle glycogen upon the fish after they leave the fishway is not known and needs investigation.

According to Black *et al.* (1962), muscle glycogen is probably the primary fuel for rapid evasive or strenuous activity since it provides the most readily mobilized source of energy. Furthermore, when utilized in severe exercise its restoration to normal levels in immature trout is remarkably slow if the fish are not fed. However, Fontaine and Hatey (1953) in examining mature, migrating Atlantic salmon found no depletion of muscle glycogen upon completion of the upstream migration. These latter authors were of the opinion that migrating salmon must have a well-adapted ability to regulate gluconeogenesis (i.e. formation of carbohydrate from protein and fat stores) in accordance with the energy demand. It is possible that the hormonal changes accompanying maturation

in migrating salmonids may considerably alter the pattern of carbohydrate metabolism normally seen in young trout. In view of the fact that migrating salmonids are in a non-feeding condition and are faced with a situation where sustained demands may be made upon energy-producing mechanisms, it indeed seems probable that rapid replenishment of muscle glycogen can occur in these fish even without feeding.

Thus until experiments are carried out to establish the prime source of energy in mature migrating fish, and the rate and means by which muscle glycogen is restored following exercise in these fish, the significance of the increased utilization of muscle glycogen in the steeper fishway cannot be ascertained. It should be noted that fish counts at the Rock Island dam on the Columbia river indicate no decline in population after 30 years of operation of a 1:10-slope fishway. The recently constructed Ice Harbour dam, which includes both a 1:16- and a 1:10-slope fishway, should provide the opportunity for direct physiological comparison under actual operating conditions.

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AGE AND LENGTH COMPOSITION OF THE SARDINE
CATCH OFF THE PACIFIC COAST OF THE UNITED
STATES AND MEXICO IN 1961-62¹ANITA E. DAUGHERTY
Marine Resources Operations
California Department of Fish and Game
andROBERT S. WOLF
U.S. Bureau of Commercial Fisheries

INTRODUCTION

This is the 16th report in a series giving age and length composition of the catch of Pacific sardines, *Sardinops caeruleus* (Girard), off the Pacific coast of North America. These have been prepared on a seasonal basis since 1941-42.

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THE FISHERY

During the 1961-62 season, 2,200 tons of sardines were landed in central California, August 1, 1961, through March 2, 1962, and 21,498 tons in southern California, September 1 through March 2. During the interseason, January 1 to the beginning of the respective seasons, landings totaled 1,596 tons. The 1961-62 period total for all California was 23,695 tons. For several prior years the season in both central and southern California had ended December 31. In 1961 it was extended to March 1, of the following year, making March 2 the last delivery date. This report, therefore, covers sardine landings of the period January 1, 1961, through March 1, 1962.

Landings during the season include both cannery and fresh fish market deliveries. Most of the latter are head or frozen and sold for bait, chiefly in the San Francisco region, where sardines are regarded as the best bait in the striped bass sportfishery.

Interseason sardine landings include not only fish sold for bait but also a special summer pack. This pack, first permitted in 1929, gives canneries an opportunity to develop packs in small cans which might compete with imported "sardines." This privilege was suspended by the Legislature in 1949 as the result of the decline in sardine landings. On June 1, 1961, the special pack again became legal, and one processor, taking advantage of this, purchased sardines during June through August for a 6½-ounce fillet pack.

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TABLE 1
Calendar Dates of Lunar Months During 1961-62

<i>Lunar month</i>	<i>Lunar period</i>	<i>Dates</i>
"January" -----	510*	January 2—January 31
"February" -----	511	February 1—March 1
"March" -----	512	March 2—March 30
"April" -----	513	March 31—April 29
"May" -----	514	April 30—May 28
"June" -----	515	May 29—June 27
"July" -----	516	June 28—July 27
"August" -----	517	July 28—August 25
"September" -----	518	August 26—September 24
"October" -----	519	September 25—October 23
"November" -----	520	October 24—November 22
"December" -----	521	November 23—December 22
"January" -----	522	December 23—January 21 (1962)
"February" -----	523	January 22—February 19
"March" -----	524	February 20—March 20 †

* Lunar months have been numbered serially since "November" 1919.

† 1961-62 period ended March 1.

In Baja California, cannery fishing is permitted throughout the year. For this report, the period is divided into two parts, season and inter-season, the dates coinciding with those of southern California. Season and interseason landings were 8,551 tons and 11,752 tons respectively, a period total of 20,303 tons.

Central California

The season opened August 1 in central California (Point Arguello northward), but for the most part the boats remained in port until the latter part of the month because fish were scarce. Landings at Monterey, Moss Landing, and Morro Bay during the first dark (Table 1) were 197 tons. During "September," 349 tons were landed; during "October," 524 tons; during "November," 324 tons; during "December," 104 tons; during "January," 485 tons; and during "February," 217 tons. The total for the region was 2,200 tons.

A sardine price of \$50 per ton was agreed upon at Monterey well in advance of the season. Southern California fishermen subsequently agreed upon the same price, an increase of \$15 over the preceding season. Mixed sardines and mackerels brought \$45, straight mackerel \$42.50. In addition to the fish actually caught in central California about 2,000 tons were trucked there from southern California.

Two Monterey canneries closed shortly after the beginning of the season, leaving five plants operating in central California: one at San Francisco, one at Moss Landing, and three at Monterey.

One large (60 feet or over) and one small purse seiner and 15 lampara boats fished in central California only, while an additional nine large and two small purse seiners fished both in central and in southern California.

Southern California

In southern California, the season opened September 1, and the fleet began fishing the night of September 4. The union-cannery agreement which accepted the central California prices, further stipulated that there be a minimum limit of 40 tons on sardines and 20 tons on mackerels. In actual practice, the sardine limit was either higher than the

or most of the time, non-existent, while the mackerel limit remained at 20 tons, and limits on mixed mackerels and sardines were usually 30 to 40 tons.

Southern California landings were highest in the opening dark, "September," with 7,612 tons. In "October" they were 3,754 tons; in "November," 2,555 tons; in "December," 3,884 tons; in "January," 1,664 tons; in "February," 1,987 tons; and in "March," 42 tons. The total was 21,498 tons, of which 29 tons were caught off Baja California.

Beginning November 1, sardine schools were so difficult to find that mostly mackerels were landed. However, when a boat did find a school of sardines, it was frequently a good-sized one. On the nights of November 30-December 1 and December 1-2, fishermen found large schools of sardines off Point Hueneme and landed 2,200 tons in two days. One boat wrapped a school of 250 tons in an area the fishermen had been avoiding because of an abundance of anchovies. A storm terminated fishing after two nights, but sardines again appeared there on the night of January 7-8, some in pure schools, others mixed with mackerel. Landings for the fleet that night were 667 tons, one boat wrapping 245 tons. On February 1, two, 100-ton loads were caught off La Jolla, and on February 2, several loads of 60 to 100 tons were caught near Cortez Bank.

Throughout the season in southern California, the fish tended to be offshore and far from port. The greatest tonnage came from San Nicolas Island and from Cortez and Tanner Banks, all rather unusual places for the sardine fleet to be working. Other catches were made at Anacapa Island, Point Hueneme, Santa Barbara Island, Santa Catalina Island, and scattered localities along the mainland from Point Dume to La Jolla.

One cannery operated at Oxnard, and six in the Los Angeles-Long Beach Harbor area.

A total of 66 boats, comprising 41 large purse-seiners and 25 small purse-seiners and lampara boats, fished exclusively in southern California. In addition, nine large and two small purse-seiners from central California joined the southern fleet for part of the season. Altogether, 94 boats, 51 large and 43 small, operated in California compared to 104 the previous season.

Baja California

Baja California landings were 2,777 tons during the September dark; 2,276 tons during "October"; 1,941 tons during "November"; 1,095 tons during "December"; 91 tons during "January"; and 371 tons during "February," for a total of 8,551 tons. Landings were made at six canneries in the Ensenada region and one on Cedros Island and were about equally divided between the two areas. The San Quintín cannery ceased operations at the end of "February" 1961.

Most sardine catches were made in the general vicinity of Cedros Island, particularly in the Santa Rosa-Santo Domingo area off the mainland. Some fish was hauled from there, in refrigerated boats, to plants at Ensenada.

Mexican-owned fishing vessels received \$32.60 per ton for sardines and mackerels, while American-owned vessels received \$40 per ton. Thirty-five boats fished during 1961.

TABLE 2
Length Composition of Year-classes in Sardine Samples from the Central
California Commercial Catch, 1961-62 Season

Year-class Standard length (mm)	1961	1960	1959	1958	1957	1956	1955	Totals	
								Aged	Measured
212									1
214									1
216									1
218									1
220				1				1	5
222									4
224					1			1	7
226			1		3			4	20
228				1		2		3	24
230				1	3	4		8	34
232			1		3	1		5	32
234				1	5		1	7	47
236				1	7	1	1	10	61
238				1	8	4		13	79
240				1	3	12		16	74
242					3	4	1	8	83
244				1	14	11	2	28	115
246				1	6	12	3	22	125
248				1	7	12	4	24	107
250					9	13	4	26	88
252					7	9		16	79
254					5	6		11	61
256					6	3		9	52
258					1	3		4	22
260					1	1	3	5	14
262						4		4	8
264									1
266					1			1	2
268									1
270									
272									1
Totals			2	10	93	102	19	226	1,150
Mean lengths			229	236	244	247	248	245	244

AGE AND LENGTH COMPOSITION

During the season, 1,150 fish were measured (in millimeters SL) in central California, 4,000 in southern California, and 2,200 in Baja California. Ages were determined for approximately one-fifth of the (Tables 2-4).

Central California sardines ranged from 212 to 272 mm SL with mean of 245 mm and an average weight of 0.468 pounds. Catches were dominated by five-year-olds (1956 year-class) which comprised 46 percent of the fish for which ages were determined, and by four-year-olds ('57 year-class) which contributed 41 percent (Figure 1, Table 8). The previous season's catch was dominated by the same year-classes but in reverse order; three-year-olds ('57 year-class) and four-year-olds ('56 year-class), contributing 52 and 34 percent, respectively.

TABLE 3

Length Composition of Year-classes in Sardine Samples from the Southern California Commercial Catch, 1961-62 Season

Year-class	1961	1960	1959	1958	1957	1956	1955	1954	Totals	
									Aged	Measured
Standard length (mm)										
176										1
178										1
180										2
182										2
184										2
186				1					1	3
188			2						2	3
190			1	1					2	7
192										19
194			1	1					2	15
196			2	1					3	20
198			2	4	1	1			8	26
200		1		1	4				6	33
202			4	2	5				11	55
204			2	7	4	1		1	15	56
206				6	2	1			9	79
208			3	9	5	1			18	99
210			3	11	8	2			24	119
212			2	9	14	3			28	123
214				8	15	4	1		28	140
216			3	15	11	11			40	180
218				12	24	2			38	209
220			1	11	26	7	1		46	235
222			1	7	20	14	1		43	270
224				13	39	9	3		64	320
226				10	32	17	2		61	335
228				7	38	28	3		76	339
230				6	35	25	2		68	317
232				1	23	14	1		39	259
234				5	24	18			47	220
236				4	12	17			33	163
238				2	13	18	1		34	133
240					7	5			12	80
242					5	5			10	58
244					3	1			4	31
246					2	1			3	17
248					1		1		2	16
250				1					1	5
252					1				1	4
254						1			1	4
Totals		1	27	155	374	206	16	1	780	4,000
Mean lengths			205	217	225	229	228		224	224

Southern California sardines ranged from 176 to 254 mm with an average length of 224 mm and an average weight of 0.326 pounds. The previous season's catch was dominated by threes ('56 year-class).

Baja California sardines were smaller than those off California. Sizes ranged from 132 to 226 mm, with the mean at 174 mm, and an average weight of 0.210 pounds. Age-three ('58 year-class), and age-four ('57 year-class) fish dominated the catch, contributing 34 and 40 percent respectively.

TABLE 4
Length Composition of Year-classes in Sardine Samples from the
Baja California Commercial Catch, 1961-62 Season

Year-class Standard length (mm)	1961	1960	1959	1958	1957	1956	1955	Totals	
								Aged	Measured
132									1
134									
136									
138									3
140		1	1					2	7
142			1					1	5
144			1					1	4
146			3					3	16
148		1	6	1				8	19
150		2	4	1				7	29
152			1		1			2	32
154		1	3	3	1			8	61
156		2	6	6				14	69
158			9	4				13	68
160			10	5				15	89
162			12	10	3			25	100
164		1	12	9	3	2		27	122
166		1	7	14	2	2		26	122
168		2	8	11	3			24	128
170			7	10	6	1		24	121
172			6	10	5			21	128
174			7	12	8	2		29	152
176			8	10	7			25	109
178			3	11	2	1	1	18	105
180			3	6	6			15	87
182				4	8	2		14	66
184			3	3	1			7	62
186			3	1	2	1		7	44
188				12	2	1		15	46
190			3	5	1			9	44
192			4	4	2	1		11	52
194			2	3	4	1		10	48
196			2	4	2	1		9	49
198			1	3	2			6	35
200			1	7	3			11	42
202			1	2	2	3		8	32
204				3	2	1		6	29
206			1	1		1		3	26
208				3	1			4	11
210				2	1			3	14
212					1			1	5
214					1	1		2	6
216									4
218						1		1	2
220									3
222									1
224									1
226					1			1	1
Totals		11	139	180	83	22	1	436	2,200
Mean lengths		156	168	177	182	188		175	174

TABLE 5
Length Composition of Year-classes in Sardine Samples from the
Central California Interseason Catch, 1961

Year-class Standard length (mm)	1961	1960	1959	1958	1957	1956	1955	Totals	
								Aged	Measured
190	---	---	---	---	---	---	---	---	1
192	---	---	---	---	---	---	---	---	2
194	---	---	---	---	---	---	---	---	---
196	---	---	---	---	---	---	---	---	---
198	---	---	---	---	---	---	---	---	1
200	---	---	---	---	---	---	---	---	1
202	---	---	---	---	---	---	---	---	---
204	---	---	---	---	---	---	---	---	1
206	---	---	---	---	---	---	---	---	1
208	---	---	---	---	---	---	---	---	---
210	---	---	---	---	---	---	---	---	2
212	---	---	---	---	---	---	---	---	---
214	---	---	---	---	---	---	---	---	3
216	---	---	---	---	1	---	---	1	2
218	---	---	---	---	---	---	---	---	1
220	---	---	---	---	1	---	---	1	6
222	---	---	---	2	---	---	---	2	3
224	---	---	---	---	1	1	---	2	6
226	---	---	---	---	---	1	---	1	2
228	---	---	---	---	2	---	---	2	3
230	---	---	---	2	---	---	---	2	6
232	---	---	---	---	1	---	---	1	4
234	---	---	---	---	---	---	---	---	5
236	---	---	---	---	---	---	---	---	9
238	---	---	---	---	1	---	1	2	10
240	---	---	---	---	1	1	---	2	8
242	---	---	---	---	2	---	---	2	13
244	---	---	---	1	---	1	---	2	11
246	---	---	---	1	2	---	1	4	10
248	---	---	---	---	---	---	---	---	10
250	---	---	---	2	---	---	---	2	8
252	---	---	---	---	---	---	---	---	4
254	---	---	---	---	---	---	---	---	2
Totals	---	---	---	8	12	4	2	26	135
Mean lengths	---	---	---	237	234	234	242	235	235

TABLE 6
Length Composition of Year-classes in Sardine Samples from the
Southern California Interseason Catch, 1961

Year-class Standard length (mm)	1961	1960	1959	1958	1957	1956	1954	Totals	
								Aged	Measured
164									1
166									1
168									
170									
172		1						1	1
174									
176									
178									
180									3
182									
184									1
186				1				1	1
188									6
190									6
192		1		2				3	8
194									10
196			1	2				3	10
198			2					2	11
200				1				1	12
202				1	1			2	12
204				3	1	1		5	15
206			1		3			4	21
208				1				1	13
210				3	1			4	16
212				1	1			2	21
214			1	2	1			4	16
216					1	2		3	21
218				2	1			3	16
220				3	3			6	17
222			1	1	4	1		7	19
224					1			1	16
226				3	2	3		8	36
228					4	1		5	16
230									11
232			1	1	3			5	13
234					3			3	8
236									5
238					1	1		2	5
240				1				1	3
242									1
244									
246						1	1	2	3
Totals		2	7	28	31	10	1	79	375
Mean lengths		182	209	212	222	225		217	214

TABLE 7
Length Composition of Year-classes in Sardine Samples from the
Baja California Interseason Catch, 1961

Year-class	1961	1960	1959	1958	1957	1956	1955	1954	Totals	
									Aged	Measured
Standard length (mm)										
140			1						1	1
142										1
144										3
146										5
148		1							1	5
150		2							2	9
152		1							1	10
154										18
156		2							2	21
158			1	4					5	21
160			5	4					9	33
162			7	4	2				13	43
164			5	3	2				10	58
166			6	9	3				18	71
168			8	3	2	1			14	97
170			7	7	3				17	72
172			5	8	2				15	99
174			5	12	3	1			21	96
176			4	9	6	2			21	103
178			7	5	5	1			18	119
180			8	9	8	2			27	105
182			3	6	7	2			18	107
184			2	12	6	2	1		23	85
186		1	9	9	3				13	61
188			2	4	3	1			10	66
190			1	6	3				10	51
192			1	1	2				4	35
194			1	2		1			4	31
196				4	1				5	18
198					2				2	10
200			1	1	3	1			6	16
202			1		1	1			3	10
204					1	1			2	5
206										4
208					1	1			2	4
210										1
212										1
214										
216										
218								1	1	2
220										2
222										1
Totals		7	81	122	69	17	1	1	298	1,500
Mean lengths		157	173	177	181	186			177	176

TABLE 8

Age and Year-class Composition of the Sardine Catch in the 1961-62 Season

	Catch		Number of fish in thousands by age and year-class							
	Tons	Number	0 1961	1 1960	2 1959	3 1958	4 1957	5 1956	6 1955	7 1954
Central California										
"August".....	197	823					313	197	313	
"September".....	349	1,357				73	354	737	193	
"October".....	524	2,089				119	1,069	829	72	
"November".....	324	1,274					433	663	178	
"December".....	104	545			36	109	305	95		
"January".....	485	2,387					1,003	1,277	107	
"February".....	217	1,018					427	545	46	
Total Central California.....	2,200	8,493			36	301	3,904	4,343	909	
Percent.....		100.00			0.38	3.17	41.12	45.75	9.58	
Southern California										
"September".....	7,612	46,119		46	922	7,010	22,068	12,821	2,260	92
"October".....	3,754	23,143			1,803	4,360	11,109	5,531	340	
"November".....	2,555	16,117			806	4,255	8,574	2,450	32	
"December".....	3,884	23,546		85	1,114	6,593	10,746	4,624	257	127
"January".....	1,664	9,955			100	1,832	4,380	3,524	119	
"February".....	1,987	11,981			266	1,997	5,405	4,313		
"March".....	42	205					107	82	16	
Total Southern California.....	*21,498	131,066		131	5,011	26,047	63,289	33,345	3,024	219
Percent.....		100.00		0.10	3.82	19.87	48.29	25.44	2.31	0.17
Total California	23,698	140,559		131	5,047	26,348	67,193	37,688	3,933	219
Percent.....		100.00		0.09	3.59	18.75	47.80	26.81	2.80	0.16
Baja California										
"September".....	2,777	28,749		267	8,817	11,693	6,440	1,532		
"October".....	2,276	21,972		923	5,493	9,931	4,614	1,011		
"November".....	1,941	22,016		661	9,687	8,806	2,862			
"December".....	1,095	11,288		338	4,685	3,669	1,975	395	226	
"January".....	91	789		51	351	280	91	16		
"February".....	371	2,545	10	10	632	957	631	285		20
Total Baja California.....	8,551	87,359	10	2,250	29,665	35,336	16,613	3,239	226	20
Percent.....		100.00	0.01	2.57	33.96	40.45	19.02	3.71	0.26	0.02
TOTAL.....	32,219	227,918	10	2,381	31,712	61,684	83,806	40,927	4,159	239
Percent.....		100.00		1.0	15.2	27.1	36.8	18.0	1.8	0.1

* 29 tons were caught off Baja California

TABLE 9
Age and Year-class Composition of the Sardine Catch
in the 1961 Baja California Interseason

	Catch		Number of fish in thousands by year-class							
	Tons	No.	1961	1960	1959	1958	1957	1956	1955	1954
Baja California										
"January"-----	1,858	21,035			12,762	3,645	3,507	1,121		
"February"-----	757	8,568			5,198	1,485	1,428	457		
"March"-----	1,080	12,222			7,416	2,118	2,037	651		
"April"-----	2,089	21,313			2,664	11,509	6,287	853		
"May"-----	663	7,307			2,375	3,434	1,169	329		
"June"-----	3,255	29,528			4,060	12,107	9,375	3,248	369	369
"July"-----	900	9,574		510	4,021	3,575	1,468			
"August"-----	1,150	10,064		144	2,962	4,371	2,185	402		
Total-----	11,752	119,611		654	41,458	42,244	27,456	7,061	369	369
Percent-----		100.00		0.54	34.66	35.33	22.95	5.90	0.31	0.31

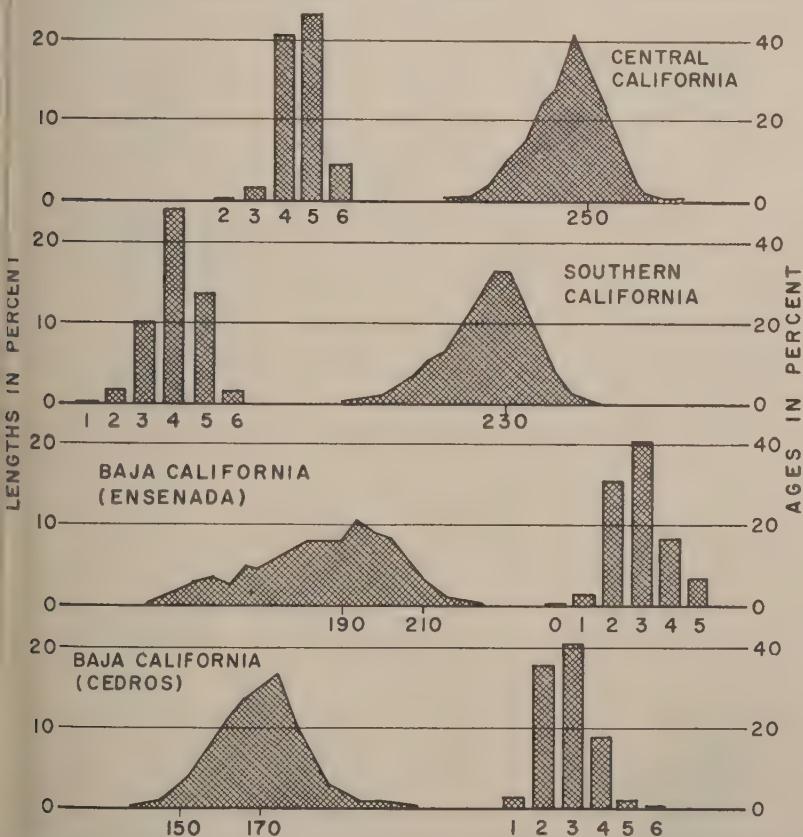


FIGURE 1. Percentage age and length composition of sardines sampled during the 1961-62 season by regions of capture. Length data are plotted by 4 mm intervals.

Interseason fish measurements included 135 fish from central California, 375 from southern California, and 1,500 from Baja California (Tables 5-7). Ages were not determined for the interseason catches of central and southern California because the results were considered likely to be misleading. The interseason catch of Baja California, where the fishery is a year around endeavor, was composed principally of '55 year-class (35 percent); '58 year-class (35 percent), and '57 year-class (23 percent) sardines (Table 9).

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**Graphic Representation of Confidence Intervals
for Petersen Population Estimates**

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Graphic Representation of Confidence Intervals for Petersen Population Estimates

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ABSTRACT

Probable confidence intervals for Petersen population estimates play an important part in decisions concerning the number of animals that must be marked and the size of the catch from which recaptures must be obtained. Requirements for an acceptable confidence interval may be so difficult to satisfy as to make a study impractical, even though the confidence interval itself is based only upon magnitude of numbers and not upon their accuracy. Graphs of the changes in confidence intervals from large to small as the magnitudes of marks applied, marks recovered, and catch change from small to large are presented to give perspective for the planning and development of Petersen population estimates. Confidence intervals were estimated by use of published formulas, tables, and graphs.

INTRODUCTION

The Petersen method of estimating population size is designed for use with only one observation each for number of marks available, number of marks recovered, and size of catch.

The confidence interval is based on these values elaborated according to statistical theory of sampling distributions. The magnitude of the individual elements or combinations thereof treated as random variables control the size of the confidence interval. Accuracy of sample components in the sense that all marks released may not be available for capture, all marks recovered may not be reported, or the entire catch may not be censused, affects the confidence interval only as it changes the magnitude of the basic parts. As the values of individual elements change from small to large, associated confidence intervals change from large to small. Therefore, without making any statement concerning the accuracy of components, it is possible to construct the range of sizes that the confidence interval will take as the magnitudes of individual values are varied. I have altered the magnitudes of marks released, marks recovered, and size of catch systematically without conducting marking experiments, and estimated the accompanying changes in size of the confidence interval. This material, presented in graphic form, is intended to facilitate the planning and development of population studies. It supplements Ricker's (1958) discussion of the assumptions that must be carried for Petersen population estimates and

methods of evaluating and improving the accuracy of sample components.

SELECTED SOURCES OF MATHEMATICAL PROCEDURES

Clopper and Pearson (1934) presented two graphs based on the binominal distribution from which confidence intervals for a Petersen population estimate can be calculated if the marked-unmarked composition of a single small sample from the population is known.

The situations covered by their work were extended by Ricker (1937), who indicated that the Poisson distribution is appropriate when the marked-unmarked ratio is small: less than 0.01 and in some cases less than 0.05; or in the section of the Clopper-Pearson graphs where interpretation becomes difficult due to the smallness of this ratio. Ricker (1937) presented a table from which confidence intervals can be derived for numbers of recovered marks up to 50. For recaptures numbering greater than 50, the normal approximation to the Poisson distribution justified by Pearson (see Ricker, 1937) was recommended. Adams (1959) explained in detail the use of the Clopper-Pearson binomial-based graphs, and adapted a Poisson-based graph from Ricker (1937).

Chapman (1948), by a different mathematical treatment, arrived at a table which produces generally somewhat smaller confidence intervals based on the Poisson distribution than does that of Ricker (1937). For numbers of recoveries greater than 50, Chapman (1948) suggested use of the Wilson-Hilferty

chi-square approximation to the Poisson distribution which can be interpolated from a table he gave for number of recoveries up to 100.

Both Chapman (1951) and Bailey (1951) proposed modified formulas that produce practically indistinguishable, almost unbiased direct sampling estimates of the population size according to Ricker (1958). Bailey's formula for estimating the large-sample sampling variance is reported in Ricker (1958) as formula 3.8.

METHODS OF ESTIMATION

Regardless of the reference source, Ricker's (1958) symbolism is used here wherever applicable:

M = number of fish marked

R = number of recaptured marks

C = catch or census sample (contains R)

N = size of population at time of marking

$\hat{N}$ = estimate of N

C.I. = confidence interval or number of units between the upper and lower 95 percent confidence limits.

Selection of the distribution or approximation thereto appropriate for estimating confidence intervals for Petersen population estimates is obtained from Chapman (1948) except for one modification. Although the Wilson-Hilferty chi-square approximation to the Poisson distribution would produce a slightly smaller confidence interval than the normal approximation for numbers of recoveries greater than 100 (Douglas G. Chapman, personal communication), I consider the use of the latter more practical in the absence of tabled values in that range for the former.

The source of the method used to estimate confidence intervals for each category is indicated in Table 1.

Confidence intervals were obtained by subtracting the lower 95 percent confidence limit from the upper 95 percent confidence limit. C.I./ N was selected as the form for presenting this material. Besides relating the confidence interval to population size, the form produces a constant value for all N 's at given C and R . The confidence interval derived from the large-sample sampling variance shown by Ricker (1958) as formula 3.8 demonstrates the latter point:

$$\begin{aligned} \text{C.I.} &= \{\hat{N} + 1.96[V(\hat{N})]^{1/2} \\ &\quad - \{\hat{N} - 1.96[V(\hat{N})]^{1/2}\} \\ &= \hat{N} 1.96[(C-R)/(C+1)(R+2)]^{1/2} [2 \\ \text{C.I.}/\hat{N} &= 3.92[(C-R)/(C+1)(R+2)]^{1/2} \end{aligned}$$

If C and R are given, the right-hand side of the equation is a constant regardless of the value of $\hat{N}$.

USE OF GRAPHS

Figures 1-4 show the effect of changing C and R/C values on C.I./ N . Values of R not given in the figures can be obtained if one or more of the curves of R/C shown can be intersected by a line perpendicular to the axis through the point being sought. For instance, in Figure 3 given $C = 40,000$ and $R/C = 0.001$, similar changes in C.I./ N are achieved by increasing either C or R/C five fold. In the first case $C = 5(40,000) = 200,000$, $R/C = 0.001$, and C.I./ $N \approx 0.2$ and in the second case $C = 40,000$, $R/C = 5(0.001) = 0.005$, and C.I./ $N \approx 0.28$. If R

TABLE 1.—Criteria for estimating 95 percent confidence intervals and sources of mathematical procedures.

Catch	Recoveries ¹ catch	Distribution or ¹ approximation thereto	Mathematical procedure	Source	Shown in figure
$C \leq 500$	$R/C \leq 0.1$ $R/C > 0.1$	Poisson approx. Binomial	Tables 1 and 2 Clopper-Pearson graph	Chapman, 1948 Adams, 1951	1
$500 < C \leq 1,000$	$R/C \leq 0.075$ $R/C > 0.075$	Poisson approx. Normal approx.	Tables 1 and 2 Formula 3.8	Chapman, 1948 Ricker, 1958	2
$C > 1,000$	$R/C \leq 0.05$ and/or $R \leq 100$ $R/C \leq 0.05$ and $R > 100$ ² $R/C > 0.05$ and $R > 100$	Poisson approx. Normal approx. to Poisson Normal approx.	Tables 1 and 2 Formula 6 Formula 3.8	Chapman, 1948 Ricker, 1937 Ricker, 1958	3 and

¹ From Chapman (1948) except ² as noted in text.

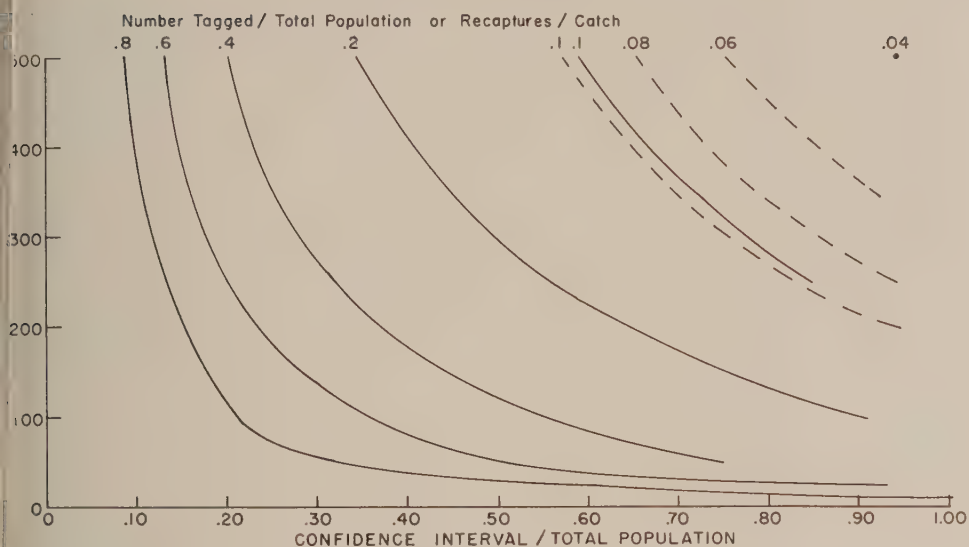


FIGURE 1.—C.I./N values for populations where $C \leq 500$, $R/C \leq 0.1$ --- and $C \leq 500$, $R/C > 0.1$ —.

0.00042 and $C = 100,000$, put $0.00042/0.0003 = 1.4$, multiply C by the quotient which is $1.4(100,000) = 140,000$, enter Figure 3 at $R/C = 0.0003$ and $C = 140,000$, and read $C.I./N \approx 0.63$.

Information required to use the curves must consist of at least a cursory knowledge of the

population size, the number of fish that can be marked, and the catch or census sample. The opinion of an experienced biologist may suffice as a starting point if no earlier studies or preliminary marking work has been done from which probable values for N , M , and C may be deduced.

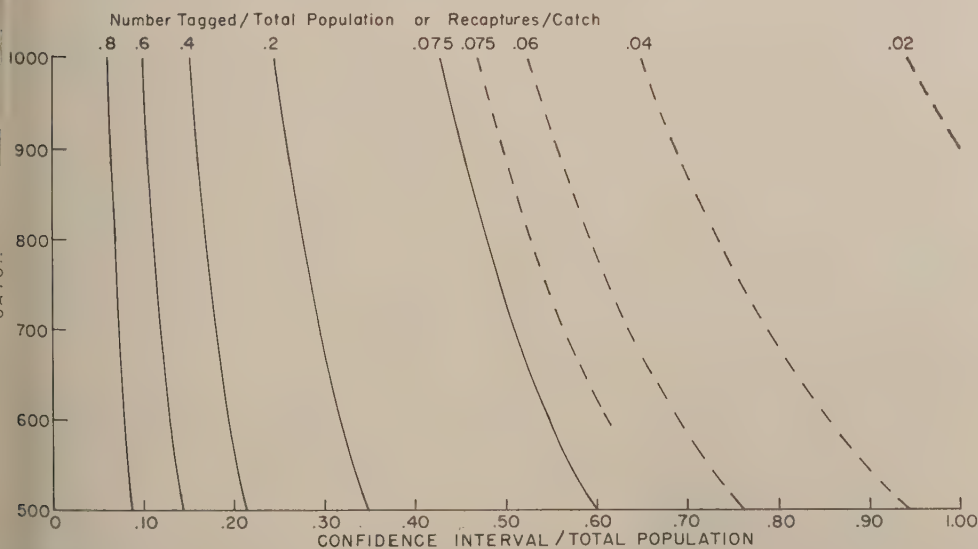


FIGURE 2.—C.I./N values for populations where $500 < C \leq 1,000$, $R/C \leq 0.075$ --- and $500 < C \leq 1,000$, $R/C > 0.075$ —.

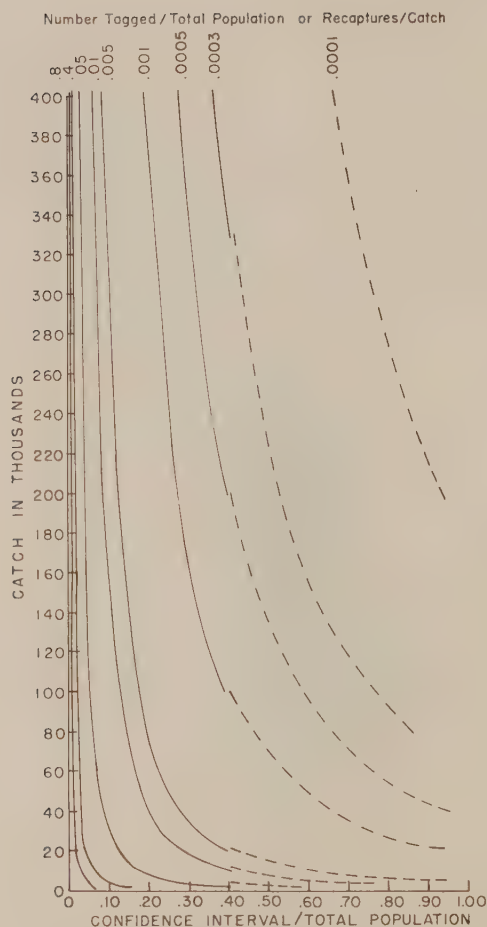


FIGURE 3.—C.I./N values for populations where $C > 1,000$, $R/C \leq 0.05$, $R < 100$ ---, and $C > 1,000$, $R/C \leq 0.05$, $R > 100$ or $C > 1,000$, $R/C > 0.05$, $R > 100$ —.

An investigator can control the size of the confidence interval for a Petersen population estimate by the number of marks applied and the size of the catch from which recaptures are obtained, or by both of these means. The smallest C.I./N for given $M + C$ is obtained when R is made as large as possible. R is at a maximum for given $M + C$ when $M = C$. This can be shown mathematically and can be seen by inspection of the formulas for computing C.I./N. The relationship $R = MC/N$ shows that R values of the same magnitude will be obtained for all values of M and C that produce the same product.

As an example, suppose a population estimate is to be made of the number of juvenile striped bass inhabiting an estuarine nursery area as part of a fish availability study. In this case, the investigator controls both the number of fish marked and the size of the catch. If a large number, say 1,000,000 juveniles, are thought to inhabit the area, and one fishing operation is expected to yield about 5,000 fish, a C.I./N of about 0.58 would be obtained whether 5,000 are marked or 10,000 caught or vice versa. In the first case $R/C = 0.005$ and $C = 10,000$, and in the second case $R/C = 0.01$ and $C = 5,000$. Figure 4, which is an enlargement of the scale Figure 3 for catches between 1,000 and 30,000, can be used to advantage here.

The information available at this station would permit the detection of differences greater than about 290,000 individuals if population estimates in succeeding years can be made with an accuracy at least as good as that in the year just described. It will not be possible to show a difference between two population estimates if the confidence interval for one estimate overlaps the other estimate. The quantity 290,000 is obtained by halving C.I./N and multiplying the result by N . Where the normal distribution applies, the confidence interval is divided equally on either side of the population estimate. This is not true for binomial and Poisson distributions as shown graphically by Adams (1951), but nevertheless can be used as a guide for adjusting effort to obtain desired accuracy where these distributions apply.

If, in the example, it is necessary to reduce detectable differences from 290,000 to 100,000, the best numbers of fishing operations to release (M) and recapture (C) marks can be estimated. Solve $\frac{1}{2}(\text{C.I./N})(1,000,000) = 100,000$ and obtain C.I./N = 0.20. If the catch from one fishing operation, 5,000 fish, is marked, $M/N = R/C = 0.005$ and C must be 80,000 to obtain a C.I./N = 0.20 (Figure 3). Table 2 shows the number of fishing operations for recapturing marks required to maintain C.I./N $\approx$ 0.20 as the number of fishing operations for marking are increased over at a time.

The final choice of the number of fishing

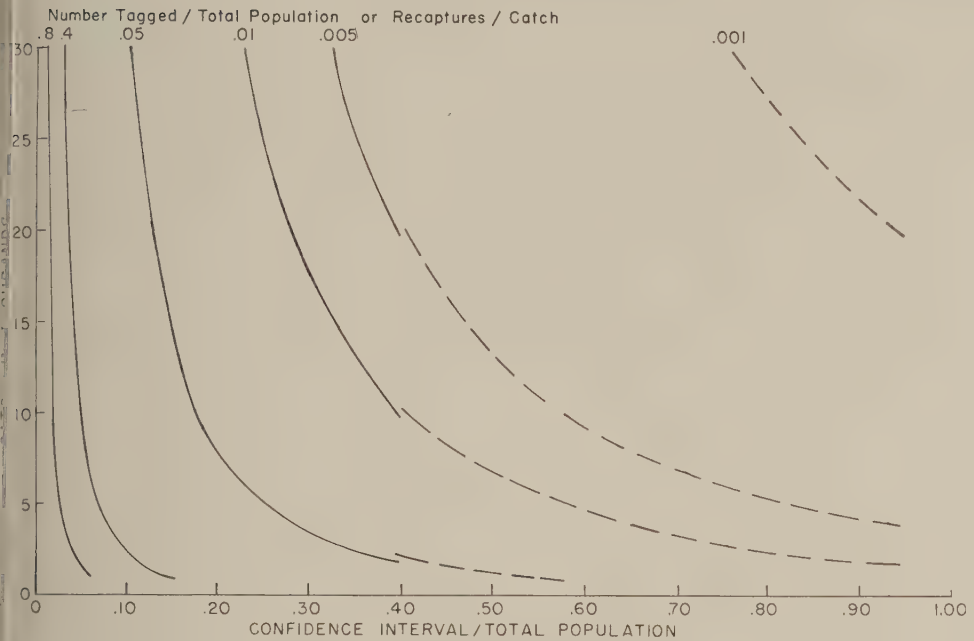


FIGURE 4.—Enlargement of scale shown in Figure 3 for catches between 1,000 and 30,000.

operations for marking and the number of fishing operations for recapturing marks could be made to minimize the greatest sources of error such as marking mortality or mark identification with a reasonable safety margin, and at the same time minimize the cost in equipment and personnel.

As a second example, suppose that a small-mouth bass population is thought to consist of about 2,000 fish. Further, let the expected catch of 400 to 600 be beyond the control of the investigator as would be the case in a sport fishery. Say that about 80 marks can be applied. Figure 1, which is appropriate for $C = 400$ and M/N or $R/C = 0.04$ (Table 1), shows that $C.I./N$ will be greater than 1.00. Figure 2, which is appropriate for $C = 600$ and $R/C = 0.04$ (Table 1), shows that $C.I./N$

will be about 0.86. If the number of fish marked is doubled, R/C becomes 0.08 and at $C = 400$, $C.I./N$ is about 0.73.

At $C = 600$, $C.I./N$ must be obtained in the same way as was done in the previous example. The procedure is as follows: $0.08/0.075 = 1.07$, $1.07(600) = 642$, and, entering Figure 2 at $R/C = 0.075$ and $C = 642$, $C.I. \approx 0.59$.

Confidence intervals of the magnitude described in this example make it difficult to follow changes in population size closely; however, investigation objectives usually dictate the accuracy required. The mere detection of eruptive or catastrophic population changes, for instance, could be accomplished with rather wide confidence intervals.

Information available at any stage during the development of a Petersen population estimate can be made more valuable as a basis for biological or logistic decisions if the statistical probability of accuracy is used to supplement the basic requirements of the method discussed by Ricker (1958). Figures 1-4 make it possible to do this rapidly and comprehensively for the values shown.

TABLE 2.—Mark and catch relationships required to obtain $C.I./N \approx 0.20$ for $N = 1,000,000$ fish

Number of fishing operations for marking	Number of fish marked	Number of fishing operations for recapture marks (C)	Number of fish caught	R/C or M/N
1	5,000	16	80,000	0.005
2	10,000	8	40,000	0.010
3	15,000	5	25,000	0.015
4	20,000	4	20,000	0.020

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PRODUCTIVITY OF SOCKEYE SALMON NURSERY LAKES IN WESTERN ALASKA

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Among Alaska's most valuable renewable natural resources are the sockeye salmon runs of Western Alaska. During the last 10 years these runs have been subjected to large-scale commercial fishing. Regulation of the inshore fishery has been complicated somewhat in recent years because of the development of the Japanese high-seas salmon fishery. This has stimulated a short-term but intensive research program (1961-1962) which had as one of its objectives the determination of carrying capacities of spawning grounds and lake nursery areas.

For this purpose detailed limnological surveys, including measures of basic productivity, were conducted in all major sockeye producing systems. Also undertaken were studies of the distribution, abundance, growth, and survival of young sockeye in nursery lakes. Aerial and ground surveys were carried out to determine the distribution of spawning sockeye and the relative importance of spawning areas within each system.

Evidence to date seems to indicate that available spawning area does not place an upper limit on production in most river systems but rather that production is limited by the capacity of nursery lakes for rearing sockeye juveniles. The pattern of utilization of nursery areas differs from system to system, and some potential nursery areas are not fully utilized in spite of comparable rates of basic productivity. Species composition of associated fishes (potential predators and competitors) in some instances differ markedly between lakes and lake basins within the same river system. Rates of basic productivity were higher in 1962 than in 1961. This was reflected in higher growth rates of young sockeye salmon in 1962.

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ECOLOGICAL OBSERVATIONS OF MACRO- INVERTEBRATES IN TAMPA BAY, FLORIDA 1961 - 1962¹

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ABSTRACT

A checklist is presented which includes 78 genera and 82 species of sponges, annelids, sipunculids, decapod crustaceans, gastropods, pelecypods, cephalopods, echinoderms, and ascidians. All specimens were collected in Tampa Bay, Florida, and adjacent waters from August 1961 to August 1962. Their occurrence, distribution, and relation to bottom type are discussed. Observed temperature and salinity ranges for most of the organisms are given. This information is expected to be useful in evaluating faunistic changes resulting from man-made alterations in Tampa Bay, Florida.

INTRODUCTION

The combined value of commercial and sport fisheries in Florida is estimated to be in the vicinity of \$300,000,000 per year (Ellis, Rosen and Moffett, 1958). Many of the fish, shellfish, and crustaceans supporting these fisheries are dependent upon estuaries during their early development (Skud and Wilson, 1960). Rapid urbanization of the Tampa Bay water front and associated dredging and bulkheading is modifying the estuary and posing a possible threat to the natural habitat of resident biota.

Planktonic larval stages of invertebrates play an important role in the food chain of sea animals (Davis, 1955). Adult invertebrates serve as food for other fauna and many of them, such as pink shrimp, blue crabs, stone crabs, scallops, and oysters are vitally important in the economy of our nation.

The information in this report was obtained in connection with an ecological study of Tampa Bay and adjacent waters. The occurrence of macro-invertebrates in Tampa Bay and associated ecological data are presented.

Macro-invertebrates of the northern Gulf of Mexico have been studied (Ladd, 1951; Hedgpeth, 1953; Carpenter, 1956; Ladd, Hedgpeth and Post, 1957; Parker, 1955, 1956, 1959a, 1959b and 1960), but they have received very little attention along the west coast of Florida. Prior to this investigation, no extensive invertebrate surveys had been conducted in Tampa Bay. One of the earliest observations of invertebrates in the Bay system was made in Boca Ciega Bay, Florida by Heilprin (1887). Dawson

¹Contribution No. 7 from the Bureau of Commercial Fisheries Biological Station, St. Petersburg Beach, Florida.

(1953) described the locations of the oyster bars in Tampa Bay. A brief account of some invertebrates and associated ecologic data in Boca Ciega Bay was given by Hutton, Eldred, Woodburn and Ingle (1956). Woodburn, Eldred, Clark, Hutton and Ingle (1957) contributed by reporting a live-bait-shrimp study of the west coast of Florida, including the Tampa Bay area. Very brief references on crustaceans in Tampa Bay and vicinity were made by Rathbun (1918, 1925, 1930 and 1937) and Holthuis (1951 and 1952).

Two studies are of particular interest to our research since they offer comparable invertebrate data to the north and to the south of Tampa Bay. The decapod fauna of Alligator Harbor, Florida, was studied by Walker (1955), and a comprehensive survey of the macro-invertebrates of Florida Bay and White Water Bay, Florida, was conducted by Tabb and Manninger (1961).

MATERIALS AND METHODS

From August 1961 to August 1962, monthly biological and hydrological samples were collected concurrently from 42 locations in Tampa Bay (Fig. 1). Stations were selected to include as many different environmental situations as possible.

All biological specimens were collected with either a ten-foot shrimp trawl-net or a beach seine and were preserved in 10 per cent formalin.

Water samples for salinity analyses were collected with a modified Van Dorn bottle (Van Dorn, 1957) or a weighted polyethylene container. Salinity was determined by the Mohr-Knudsen method described by Knudsen (1901). Water temperatures were recorded from a Whitnall underwater thermometer (Model T 65) or with a mercury Celsius thermometer graduated to tenths of degrees.

DESCRIPTION OF STUDY AREA

The Tampa Bay System is centrally located on the west coast of Florida. Old Tampa Bay, Hillsborough Bay, Tampa Bay, Boca Ciega Bay and Terra Ceia Bay are the main components of the estuary (Fig. 1). This shallow estuary has an area of 346 square miles and the total shoreline is 212 miles in length (Olson and Morrill, 1955). Ninety per cent of the estuary is less than 22 feet in depth and the mean depth is 11 feet. Mangroves constitute the predominant shore-line vegetation. Tidal exchange is responsible for the principal circulation of bay water; fluvial discharge plays only a subordinate role (Goodell and Gorsline, 1960). The fresh water addition to Tampa Bay originates mainly from the Hillsborough, Alafia, Little Manatee, and Manatee Rivers (Dragovich and May, 1962). The mean range of tide in Tampa Bay varies from 1.9 feet at the lower end of the Bay to 2.2 feet at Tampa.



FIGURE 1. Map of Tampa Bay area showing sampling locations.

The bottom sediments of Tampa Bay were studied by Goodell and Orsline (1960). They consist of a mixture of terrigenous quartz sand and biogenic carbonate in the form of mollusk shells. Shifting of bottom materials by tidal currents has produced a relatively homogeneous sedi-

ment mass. The finer materials, mainly mud, are deposited in the bay heads or in local depressions in the bay floor, whereas coarse sand and shell particles are deposited in the channels. The bottom supports extensive seagrass and beds of *Thalassia testudinum*, *Ruppia maritima*, *Diplanthera wrightii*, *Siringodium filiforme*, and algae of many species: *Gracilaria verrucosa*, *Gracilaria* spp., *Sargassum* spp., *Ulva lactuca* and *Ulva intestinalis*. Intertidal oyster beds occur along the shore line throughout much of the Bay, and extensive submerged oyster beds are located in Old Tampa Bay.

The Tampa Bay area has a subtropical, humid climate. The average annual rainfall is 49 inches and the daily mean minimum and maximum temperatures are 17.6°C and 27.1°C, respectively (Olson and Morris, 1955). The water temperature in bay waters is closely associated with air temperature (Dragovich and Kelly, 1963). The maximum water temperature is about 32°C and is usually attained in July or August. The minimum water temperature may be as low as 10°C and is usually observed during December or January.

The temperature variations during summer and early fall months seldom exceed 1°C. During the period of this study, the mean monthly temperature did not fall below 20°C until December. A horizontal salinity gradient persists throughout the year with the maximum zone in adjacent Gulf waters and the minimum zone in the upper portion of Hillsborough Bay. The seasonal salinity changes in Tampa Bay are associated with local rainfall and land run-off. Salinity usually varies from a few parts per thousand in the Bay to 34-36 parts per thousand in adjacent Gulf waters. During the periods of heavy rainfall, areas at river mouths possess limnetic characteristics (Dragovich and May, 1962).

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BIOLOGICAL COLLECTIONS AND ASSOCIATED OBSERVATIONS

Phylum PORIFERA

Class DEMOSPONGIAE

Order DYCTYOCERATIDA

Physidea fragilis (Montagu)

Five specimens collected from September to November and during June in grass flats off Egmont Key. Cosmopolitan in distribution in tropical and temperate waters (W. D. Hartman, *in litt.*). OS² 33.15-44.45‰; OT² 20.5-27.7°C.

Order HALICHONDRIA

Halichondria bowerbanki Burton?

One specimen collected during April three and one-half miles offshore. Found in North America from south shore of Cape Cod to North Carolina. In Europe distributed in Britain, France, North Sea, and western Mediterranean (W. D. Hartman, *in litt.*). OS 33.26‰; OT 20.2°C.

Order HADROMERIDA

Cliona celata Grant

Few specimens collected from sandy bottom in Boca Ciega Bay. Found in North America from Gulf of St. Lawrence to South Carolina; west coast of Florida; St. George's Sound Florida; Louisiana and Texas. Found also on the west coast of Europe and in the Mediterranean (W.D. Hartman, *in litt.*). OS 33.19-33.57‰; OT 18.9-22.1°C.

Phylum ANNELIDA

Class CHAETOPODA

Order POLYCHAETA

Family Nereidae

Nereis sp.

Several specimens collected from sandy bottom in Old Tampa Bay, Hillsborough Bay, and Tampa Bay. Length varied from 28 to 93 mm. Found in inshore waters of Cape Sable, Florida (Tabb and Manning, 1961). OS 24.74-29.99‰; OT 18.0-29.9°C.

Phylum SIPUNCULIDA

Siphonosoma cumense (Keferstein)

One specimen, 125 mm in length, collected from sandy type bottom in Boca Ciega Bay. Widely distributed species; first described from Cumana in Venezuela; since then reported from Gulf of Mexico, Indian Ocean and Indonesia (A. C. Stephen, *in litt.*). OS 31.55‰; OT 16.5°C.

²Abbreviations OS and OT are used for observed salinity in parts per thousand and observed temperature in degrees of Celsius.

Phylum ARTHROPODA

Class CRUSTACEA

Subclass MALACOSTRACA

Order STOMATOPODA

Family Squillidae

Squilla empusa Say

Mantis Shrimp

Several specimens taken on sandy and mud bottom of Old Tampa Bay, Hillsborough Bay and Tampa Bay. Observed during March, April, June, October and November. Recorded at a wider salinity range (16-38‰) from Florida Bay, Florida (Tabb and Manning, 1961). Ranges from Cape Cod, Massachusetts to French Guiana (Manning, 1961). OS 24.4-29.42‰; OT 19.6-31.6°C.

Order DECAPODA

Suborder NATANTIA

Section PENAEIDEA

Family Penaeidae

Penaeus duorarum Burkenroad

Pink Shrimp

The most numerous crustacean in our trawls; observed throughout surveyed area during entire sampling period. Distribution encompasses Gulf of Mexico and Atlantic North America (Eldred and Hutton, 1960). OS 20.44-35.18‰; OT 15.8-33.0°C.

Sicyonia typica (Boeck)

Few specimens taken on sandy bottom in Boca Ciega Bay and in grass flats off Egmont Key. Carapace length varied from 6.5 mm to 9.5 mm. Range extends from North Carolina to West Indies and south to Rio de Janeiro (Holthuis, 1959). OS 33.80-35.61‰; OT 21.4-23.8°C.

Trachypenaeus constrictus (Stimpson)

Seventeen specimens collected randomly throughout sampling area. Observed from May to November. Carapace length varied from 5.4 mm to 10.5 mm. Recorded from Bermuda, Puerto Rico, Sombrero Island, Dutch Guiana, and along the east and south coasts of United States from Chesapeake Bay to Texas (Holthuis, 1959). OS 25.81-32.70‰; OT 22.3-30.3°C.

Trachypenaeus similis (Smith)

One female specimen, 8.7 mm in carapace length, collected during August in grass beds off Egmont Key (Saloman, unpubl. MS³). Known from the Gulf Coast of the United States and Mexico; from the northern Antilles, the Gulf of Paria near Trinidad and French and Dutch Guiana (Holthuis, 1959). OS 32.97‰; OT 30.3°C.

³Occurrence of the Penaeid shrimp, *Trachypenaeus similis* (Smith) in Tampa Bay, Florida. BCF Biological Station, St. Petersburg Beach, Florida.

Section CARIDEA

Unidentified caridean shrimp observed throughout area during entire sampling period.

Suborder REPTANTIA

Section MACRURA

Superfamily THALASSINIDEA

Family Callianassidae

Stomatopoda affinis Say

One specimen, 45 mm in length, collected during March from soft sandy bottom in Old Tampa Bay. Reported from similar habitat in Alligator Harbor, Florida (Wass, 1955). Occurs from Buzzards Bay, Massachusetts, to Florida and Louisiana; West Indies to Brazil (Schmitt, 1935). OS 28.57‰; OT 14.8°C.

Section ANOMURA

Superfamily GALATHEIDEA

Family Porcellanidae

Metrolisthes galathinus (Bosc)

A single specimen collected during April in a sponge three and one-half miles offshore. Reported from similar habitat in Florida Bay, Florida (Tabb and Manning, 1961) and Alligator Harbor, Florida (Wass, 1955). Found from North Carolina to Brazil; Taboguilla Island, Panama; Culebra, Vieques and St. Thomas (Schmitt, 1935). OS 33.26‰; OT 20.2°C.

Metrolisthes armatus (Gibbes)

One specimen, 7.5 mm in length, collected from grass bottom area in Boca Ciega Bay. Reported also from Alligator Harbor, Florida (Wass, 1955) and Florida Bay, Florida (Tabb and Manning, 1961). Found from Bermuda and Florida to Brazil, lower California to Peru; Indo-Pacific; Puerto Rico, and St. Thomas (Schmitt, 1935). OS 33.24 ‰; OT 21.9°C.

Superfamily HIPPIDEA

Family Hippidae

Emerita talpoida (Say)

Sand Flea

Eleven males and four females, 9.8 to 15.2 mm in length, collected at Egmont Key beach. Common along Gulf beaches in immediate vicinity of Tampa Bay. Oviparous females observed in February. Range extends from Harwich, Massachusetts, along the east coast of Florida to Pensacola and Progreso, Mexico (Schmitt, 1935). OS 33.93-34.36‰; OT 23.2-24.0°C.

Superfamily PAGURIDEA

Family Paguridae

Pagurus pollicaris floridanus (Benedict)

This subspecies common on sandy bottom in shallow sections of Tampa

Bay and Boca Ciega Bay. Length of specimens, measured from rostrum to media postrum margin of carapace, varied from 8.2 mm to 20.0 mm. Observed during 10 months of investigation. Ovigerous females noted November and December. Favored abode appears to be the shark-eye shell, *Polinices duplicatus*. Recorded also from Florida Bay, Florida (Tabb and Manning, 1961). Found from Texas along the Gulf coasts to southernmost tip of Florida west coast (Provenzano, 1959). OS 22.74-34.04%; OT 13.5-29.6°C.

Pagurus longicarpus Say

Much more common than previous species. Found throughout entire area of investigation. Carapace length of 182 specimens varied from 2 mm to 20.6 mm. Occurred with greatest frequency in the brackish water of upper sections of the estuary. Most abundant from October through March. Ovigerous females noted from October through April. Apparently very rare in the vicinity of Cape Sable, Florida (Tabb and Manning, 1961). Distributed in the Gulf of Mexico north to Alligator Harbor and the Gulf States (Provenzano, 1959). OS 22.45-34.04%; OT 13.5-31.0°C.

Family Diogenidae

Petrochirus diogenes (Linné)

Formerly known as *P. bahamensis* (Herbst). One specimen, 42.6 mm in carapace length, collected during August at the mouth of Little Manatee River. Scarce in shallow waters of Florida west coast (Wass, 1955; Provenzano, 1959, and Tabb and Manning, 1961). Range extends from North Carolina to Brazil, including northwestern Florida (Provenzano, 1959). OT 30.2°C.

Section BRACHYURA

Subsection DROMIACEA

Family Dromiidae

Hypoconcha arcuata Stimpson

One specimen 9.5 mm in length, collected during October from sandy bottom in Tampa Bay. Recorded from Alligator Harbor, Florida (Wass, 1955). Ranges from North Carolina to Brazil (Rathbun, 1937). OS 30.26%; OT 25.9°C.

Dromidia antillensis Stimpson

Two females, one of them ovigerous, collected during April in a spot three and one-half miles offshore. Carapace widths were 13.1 mm and 18.0 mm. Reported also from Alligator Harbor, Florida (Wass, 1955). Ranges from North Carolina to Gulf of Mexico and Brazil; also found in Bermuda (Rathbun, 1937). OS 33.26%; OT 20.2°C.

Subsection OXYSTOMATA

Family Calappidae

Calappa flammea (Herbst)

Box Cr

One juvenile specimen collected in June from sandy bottom area three and one-half miles offshore. Reported also from offshore waters of Alligator Harbor, Florida (Wass, 1955). Found from southern Massachusetts to north coast of South America; also Bermuda, Puerto Rico, Culebra, and Thomas (Rathbun, 1937). OS 35.61‰; OT 25.6°C.

Family Leucosiidae

Persephona punctata (Linné) Purse Crab

One male specimen, 15.2 mm in carapace width, collected in Old Tampa Bay during August. Its scarcity also noted on the west coast of Florida (Wass, 1955). Geographic distribution extends from West Indies to Brazil (Rathbun, 1937).

Family Matutidae

Epatus epheliticus (Linné) Calico Crab

One male specimen, 64 mm in carapace width, collected from shore area of St. Petersburg Beach. Observed also along beaches of Alligator Harbor, Florida (Wass, 1955). Geographic distribution similar to previous species.

Subsection BRACHYGNATHA

Family Portunidae

Juvenile Portunids

Most prominent group of crabs numerically. All swimming crabs smaller than 40 mm in carapace width were classified as juvenile portunids. Found throughout the Bay during entire period of observation. Most abundant in brackish waters of upper Old Tampa Bay, in vicinity of river mouths and in dense *Gracilaria* aggregations. OS 7.14-35.93‰; OT 14.1-33.9°C.

Portunus gibbesii (Stimpson)

Seven males and two females collected throughout entire study area. Carapace width varied from 41.4 mm to 65.7 mm. One ovigerous female noted in Tampa Bay during June. Recorded at salinity of 38‰ in Florida Bay, Florida (Tabb and Manning, 1961). The catch of this species in the offshore waters of Alligator Harbor, Florida, exceeded that of all other portunids combined (Wass, 1955). Known from southern Massachusetts to Texas and Venezuela (Rathbun, 1930). OS 28.33-33.46‰; OT 15.2-27.7°C.

Portunus spinimanus Latreille

Two specimens collected three and one-half miles offshore. Carapace widths were 73.5 mm and 68.0 mm. Reported also from Alligator Harbor, Florida (Wass, 1955) and from Florida Bay, Florida (Tabb and Manning, 1961). Found from New Jersey to State of Santa Catharina, Brazil; Bermuda, rare (Rathbun, 1930). OS 33.26-34.72‰; OT 20.2-25.7°C.

Arenaeus cribrarius (Lamarck) Speckled Sand Crab

One female specimen collected three and one-half miles offshore in brackish waters of Old Tampa Bay, where a prosperous commercial fishery for blue crab exists. Rarely collected at the mouth of Tampa Bay and adjacent offshore waters. Largest specimen measured 200 mm carapace width. No ovigerous females observed. Common along entire west coast of Florida (Rathbun, 1930; Wass, 1955; Tabb and Manning, 1961). Found from Nova Scotia to Uruguay; uncommon north of Cape Cod; occasionally in Massachusetts (Rathbun, 1930). OS 33.91‰; OT 15.0°C.

Callinectes sapidus Rathbun Common Blue Crab

Found throughout Bay and during entire investigation. Very common in brackish waters of Old Tampa Bay, where a prosperous commercial fishery for blue crab exists. Rarely collected at the mouth of Tampa Bay and adjacent offshore waters. Largest specimen measured 200 mm carapace width. No ovigerous females observed. Common along entire west coast of Florida (Rathbun, 1930; Wass, 1955; Tabb and Manning, 1961). Found from Nova Scotia to Uruguay; uncommon north of Cape Cod; occasionally in Massachusetts (Rathbun, 1930). OS 5.57-35.93‰; OT 14.1-33.9°C.

Family Xanthidae

Neopanope texana texana (Stimpson)

Most abundant xanthid crab in area of investigation. Found predominantly on grass flats of Boca Ciega Bay, Terra Ceia Bay, and at river mouths. Carapace width of 259 males and 150 females varied from 5 to 23.5 mm and 4.8 to 21.9 mm, respectively. Ovigerous females noted during January, February, May, June, July, October and November. Male to female ratio was 1.7 to 1. A drop in numbers occurred during the hottest months—June, July and August. Also noted in Florida Bay, Florida at low salinities (Tabb and Manning, 1961). Range extends from Mosquito Lagoon, Florida southward by way of Florida Keys and Gulf coast of Texas (Rathbun, 1930). OS 7.14-35.28‰; OT 15.0-33.9°C.

Neopanope packardii (Kingsley)

Frequently collected in central and lower portions of Tampa Bay. Occasionally found in Old Tampa Bay and Hillsborough Bay. Carapace width varied from 8.9 mm to 20.2 mm. Observed salinity range much lower than that of *N. texana texana*. This phenomenon also noted in Florida Bay, Florida (Tabb and Manning, 1961). Found off southern and western Florida, Bahamas, and Cuba (Rathbun, 1930; Wass, 1955). OS 26.16-35.53‰; OT 16.4-28.0°C.

Menippe mercenaria (Say) Stone Crab

Several juveniles and adults taken throughout area of investigation. Carapace width varied from 9.7 to 84.3 mm. Primarily collected from deep areas of Hillsborough and Tampa Bays. Range extends from North Carolina to Mexico (Rathbun, 1930). OS 23.62-33.24‰; OT 15-29.7°C.

Erypanopeus depressus (Smith)

One male specimen, 8.4 mm in carapace width, taken from mud flats in upper Old Tampa Bay. Common on oyster bars in Alligator Harbor, Florida (Wass, 1961) and in Florida Bay, Florida (Tabb and Manning, 1961). Range extends from Massachusetts Bay to Florida, Texas, St. Martin, West Indies, and Bermuda (Rathbun, 1930). OS 24.38‰; OT 29.0°C.

Erypanopeus sp.

One specimen taken during October from main channel of Hillsborough Bay. OS 27.20‰; OT 27.6°C.

Propeus herbstii Milne Edwards

Collected from muddy bottom at mouth of Alafia River. Occurred during June and July at periods of low salinity. Carapace width varied from 12.1 to 38.5 mm. Three ovigerous females noted in June. Observed at low salinities (12-25‰) also by Tabb and Manning (1961). Ranges from Boston, Massachusetts to Florianopolis (or Desterro), Brazil; occasional north of New Jersey (Rathbun, 1930). OS 22.29-24.74‰; OT 20-30.5°C.

Eumnus sayi Rathbun

Two males collected at Egmont Key and three and one-half miles offshore. Carapace width 12.2 mm and 14.3 mm. Common in coastal waters of Alligator Harbor, Florida (Wass, 1955). Distribution includes North and South Carolina, west and southwest coast of Florida, Bahamas, Jamaica, Guadalupe and Curaçao (Rathbun, 1930). OS 33.19-33.26‰; OT 15.4-20.2°C.

Hexapanopeus angustifrons (Benedict and Rathbun)

One specimen, 16.6 mm in carapace width, collected from sandy bottom three and one-half miles offshore. Also observed in offshore waters off Alligator Harbor, Florida (Wass, 1955). Occurs from Vineyard Sound, Massachusetts to Gulf of Mexico (Louisiana), Bahamas and Jamaica (Rathbun, 1930).

Family Ocypodidae

Uca rapax (Smith)

Several males collected from grassy shores and mangroves of Tampa Bay and Old Tampa Bay. Carapace width varied from 13.0 to 16.9 mm. Observed also along mud flats of Florida Bay, Florida (Tabb and Manning, 1961) and Alligator Harbor, Florida (Wass, 1955). Although previously considered a subspecies of *U. pugnax*, Tashian and Vernberg (1958) showed it to be distinct from that species. Distribution encompasses Gulf of Mexico, Florida Keys and extends to Rio de Janeiro (Rathbun, 1930). OS 26.38-30.01‰; OT 18.2-27.5°C.

Superfamily OXYRHYNCHA

Family Parthenopidae

Heterocrypta granulata (Gibbes)

The Triangle Cr

Two males collected from sandy bottom in lower portion of Tampa Bay. Carapace widths 15.0 and 16.6 mm. Scarcity on the west coast of Florida also noted by Wass (1955), and Tabb and Manning (1961). Range extends from Nantucket Sound, Massachusetts to Georgia; Gulf coast of Florida, and West Indies as far as St. Thomas (Rathbun, 1925). OS 33.19-33.51‰; OT 15.4-20.4°C.

Family Maitidae

Libinia dubia Milne Edwards

Spider Cr

Most common of all spider crabs in Tampa Bay. Frequently collected in shallow beach areas and grass flats; occasionally on sand and mud bottom. Juveniles very common in dense aggregations of *Gracilaria*. Carapace width of 156 specimens varied from 7.0 to 52.5 mm. Thoracic ovigerous females noted in deeper sections of Tampa Bay during January and April. Observed in Florida Bay at a salinity range of 25 to 38‰ (Tabb and Manning, 1961). Distribution includes shallow waters from Cape Cod, Massachusetts to Texas and Cuba; also West Africa (Rathbun, 1925). OS 23.62-35.53‰; OT 14.2-32.5°C.

Metoporphaphis calcarata (Say)

Usually found in dense *Gracilaria* aggregations. Most numerous in grass flats at mouth of Little Manatee River. Occasionally noted in remaining portions of collection area. Occurred in largest numbers during late fall and winter months. Carapace width of 51 specimens varied from 4.2 to 11.3 mm. Thoracic ovigerous females noted from December through March. Wass (1955) observed ovigerous females in Alligator Harbor, Florida during March and August. Observed salinity range similar to that noted by Tabb and Manning (1961) in Florida Bay, Florida. Found from Cape Hatteras, North Carolina to Rio de Janeiro, Brazil (Rathbun, 1925). OS 26.2-34.04‰; OT 13.5-32.0°C.

Pitho anisodon (von Martens)

Occasionally collected from passes in Boca Ciega Bay, Terra Ceia Bay, and at the mouth of Manatee River. Carapace width varied from 8.6 mm to 18.2 mm. No thoracic ovigerous females observed. Reported salinities generally agree with those recorded in Florida Bay, Florida by Tabb and Manning (1961). Recorded also from Alligator Harbor, Florida (Wass, 1955). Known from Bahamas, Florida Keys, Guadalupe, and Curaçao (Rathbun, 1925). OS 31.33-35.53‰; OT 21.4-27.9°C.

Podocheila riisei (Stimpson)

Occasionally collected in Boca Ciega Bay and adjacent offshore waters.

Found predominantly on sandy bottom. One ovigerous female noted during March on grassy bottom in Boca Ciega Bay. Size of specimens varied from 6.6 to 15.7 mm. Observed occasionally in Alligator Harbor, Florida (Wass, 1955) and Florida Bay, Florida (Tabb and Manning, 1961). Occurs in shallow water (to 30 fathoms) from North Carolina along the Atlantic Coast and Caribbean Islands to Rio de Janeiro, Brazil (Cathbun, 1925). OS 32.34-33.51‰; OT 15.2-20.4°C.

Class MEROSTOMATA

Subclass XIPHOSURA

Limulus polyphemus Linné

Horseshoe Crab

Two males and one female collected. Occurred in grass flats in Boca Ciega Bay and at the mouth of Little Manatee River. Length varied from 1 mm to 51 mm. Range extends from Nova Scotia to Florida (Miner, 1950). OS 25.70-33.08‰; OT 18.9-22.2°C.

Phylum MOLLUSCA

Class PELECYPODA

Family Ostreidae

Ostrea virginica Gmelin

Eastern Oyster

One specimen taken during study. Reported from Tampa Bay (Dawson, 1953). Observed in the Shark River Estuary at salinities varying from 1 to 36‰ (Tabb and Manning, 1961). Occurs from Gulf of St. Lawrence to the Gulf of Mexico and West Indies (Abbott, 1954).

Family Cardiidae

Cardium mortoni Conrad

Morton's Egg Cockle

One specimen collected during October from sandy bottom in Boca Ciega Bay. Reported also from bay waters near Cape Sable, Florida (Tabb and Manning, 1961). Range extends from Massachusetts to Guatemala; no record from Cuba (Clench and Smith, 1944). OS 23.30‰; OT 14.9°C.

Family Pectinidae

Pecten irradians Lamarck

Atlantic Bay Scallop

Several juvenile specimens under 25 mm in length collected during April from sandy bottom areas of Boca Ciega Bay. Found in vicinity of Cape Sable, Florida at salinities ranging from 18-41‰ (Tabb and Manning, 1961). Occurs from Nova Scotia to northern half of Florida and Texas (Abbott, 1954). OS 34.43‰; OT 20.8°C.

Pecten irradians concentricus Lamarck

One specimen collected during January from sandy bottom area of Boca Ciega Bay. Ranges from New Jersey (rare) to Virginia and Georgia, and

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Louisiana to Tampa Bay, Florida (Abbott, 1954). OS 32.10‰; C
15.9°C.

Family Chamidae

Echinochama cornuta Conrad Florida Spiny Jewel B

One specimen collected during October from sandy bottom area
Tampa Bay. Occurs off coast of North Carolina and both sides of Flori
to Texas (Abbott, 1954). OS 30.26‰; OT 25.9°C.

Family Veneridae

Chione intapurplea Conrad Lady-in-waiting Ven

Two specimens collected during April three and one-half miles offshore
Occurs from North Carolina throughout the Gulf States and to the We
Indies (Abbott, 1954). OS 34.88‰; OT 19.2°C.

Chione cancellata Linné Cross-barred Ven

Frequently observed in Boca Ciega Bay where one specimen was tak
from sandy type bottom. Previously reported from study area (Hutt
et al, 1955). Observed to invade inshore waters of Cape Sable duri
periods of high salinity (Tabb and Manning, 1961). Ranges from Nor
Carolina to Florida, Texas and West Indies (Abbott, 1954). OS 28.96
OT 29.9°C.

Family Pholadidae

Martesia striata Linné Striate Martes

One specimen, 12 mm in length, collected in a small log in Boca Cie
Bay. Found from West Florida to Texas and West Indies (Abbott, 1954
OT 23.5°C.

Family Mytilidae (Mussels)

Brachidontes exustus Linné Scorched Mus

One specimen collected during study. Frequently observed througho
the brackish waters of Tampa Bay. Primarily found along mangrove roo
and in brackish algal growth. Reported from Boca Ciega Bay (Hutt
et al, 1955) and from Florida Bay, Florida (Tabb and Manning, 1961).
Known from North Carolina to the West Indies (Abbott, 1954). C
28.77‰; OT 27.1°C.

Family Arcidae

Barbatia candida (Helbling) White Bearded Arc

Several specimens collected during October from sandy bottom
Boca Ciega Bay. Occurs from North Carolina to Brazil (Abbott, 1954
OS 26.35-36.23‰; OT 25.5-27.7°C.

Anadara transversa Say Transverse Arc

Two specimens collected during September from muddy bottom an
of Hillsborough Bay. Found from south of Cape Cod to Florida ad
Texas (Abbott, 1954). OS 23.30‰; OT 27.4°C.

Family Tellinidae

Macoma tenta Say Tenta Macoma

Several specimens collected during June from muddy bottom in upper Hillsborough Bay. Length of specimens varied from 11.5 to 12.1 mm. Range extends from Cape Cod to south half of Florida and the West Indies (Abbott, 1954). OS 28.10‰; OT 29.1°C.

Family Mactridae

Mulinia lateralis Say

Collected only in brackish waters of upper Hillsborough Bay. Usually found on muddy bottom. Occurred during June, September and October. The specimens ranged in length from 12 to 15 mm. Found from New Brunswick to Texas and West Indies (Johnson, 1934). OT 23.5-27.4°C.

Class GASTROPODA

Family Bullidae

Bulla occidentalis A. Adams Common West Indian Bubble

One specimen collected in Boca Ciega Bay during October. Occurs from North Carolina to southeast Florida and the West Indies (Abbott, 1954). OT 24.91°C.

Family Columbelloidae

Anachis avara Say Greedy Dove-shell

Several specimens collected during September from grassy (*Thalassia*) bottom area of Boca Ciega Bay. Found to be dominant member of *Thalassia* community in high salinity waters (30-47‰) of Florida Bay, Florida (Tabb and Manning, 1961). Range extends from New Jersey to both coasts of Florida and to Texas (Abbott, 1954). OS 32.97-33.49‰; OT 22.4-29.8°C.

Family Marginellidae

Prunum apicinum Menke Atlantic Marginella

Common in grass flats of Boca Ciega Bay. Several specimens, varying in length from 8.7 to 12.5 mm, collected during October. Previously reported from Boca Ciega Bay (Hutton *et al*, 1956). Range extends from North Carolina to Florida, the Gulf States and West Indies (Abbott, 1954). OS 33.25-33.42‰; OT 21.9-28.0°C.

Family Potamididae

Batillaria minima Gmelin

Although very common, only one specimen collected from grass flats in Boca Ciega Bay. Reported here also by Hutton *et al* (1956). Found off southern half of Florida and West Indies (Abbott, 1954). OS 32.5‰; OT 28.0°C.

Family Nassariidae

Nassarius vibex Say Common Eastern Nassa

Very common in the area. Collected from various types of bottom in Old Tampa, Hillsborough and Terra Ceia Bays. Appears to prefer soft bottom with some vegetation. Height and width of collected specimen varied from 1.2 to 13.2 mm and 0.6 to 8.6 mm, respectively. Abundant in Florida Bay, Florida; apparently tolerating much higher salinities than here reported (Tabb and Manning, 1961). Found from Cape Cod to Florida, the Gulf States, and West Indies (Abbott, 1954). OS 25.52-33.87‰; OT 15.0-28.0°C.

Family Muricidae

Murex pomum Gmelin

Apple Murex

One specimen collected during November at mouth of Manatee River. Scarcity of this species noted in Florida Bay, Florida (Tabb and Manning 1961). Range extends from North Carolina to Florida, and the West Indies (Abbott, 1954). OS 31.33‰; OT 23.9°C.

Urosalpinx perrugata Conrad

Gulf Oyster Drill

Few specimens collected during October from sandy bottom area in Tampa Bay. Reported from Boca Ciega Bay by Hutton *et al* (1956). Known from the west coast of Florida to Louisiana (Abbott, 1954). OS 30.26‰; OT 25.9°C.

Eupleura sulcidentata Dall

Sharp-ribbed Drill

One specimen collected in Boca Ciega Bay during October. Reported here also by Hutton *et al* (1956). Noted in Florida Bay, Florida by Tabb and Manning (1961). Found only on the west coast of Florida (Abbott 1959). OS 33.98‰; OT 24.9°C.

Family Terebridae

Terebra dislocata Say

Common Atlantic Auger

Several specimens collected during September from sandy bottom area of Boca Ciega Bay and Egmont Key. Also observed to be scarce in Florida Bay collections of Tabb and Manning (1961). Range extends from Virginia to Florida, Texas and the West Indies (Abbott, 1954). OS 32.97-34.45‰; OT 27.7-27.8°C.

Family Olividae

Oliva sayana Ravenel

Lettered Olive

One specimen collected during November from sandy bottom area in Tampa Bay. Occurs from North Carolina to Florida and the Gulf States (Abbott, 1954). OS 32.57‰; OT 23.1°C.

Family Naticidae

Polinices duplicatus Say

Shark Eye

Several specimens collected in Hillsborough and Old Tampa Bay during March, June, and July. Seems to prefer muddy and soft sand

ottom. *Pagurus pollicaris floridanus* occupied numerous shells of this species. Observed in Florida Bay, Florida at a wider salinity range (24-47‰) than noted here (Tabb and Manning, 1961). Range extends from Cape Cod to Florida and the Gulf States (Abbott, 1954). OS 26.69-33.42‰; OT 18.0-29.6°C.

Velongena corona Gmelin

Crown Conch

Common on sub-tidal flats throughout Tampa Bay. Usually found partially or wholly buried in the mud. Most abundant on mud flats of old Tampa, Hillsborough, and Boca Ciega Bays. Observed to feed upon living tellins and other living and dead bivalves. Present throughout entire sampling period. Decline in catch noted during winter months. Apparent ability to tolerate a wide salinity range also observed in Florida Bay, Florida (Tabb and Manning, 1961). Length of collected specimens varied from 2.0 to 8.6 cm, with an average of 5.6 cm. Previously reported from Boca Ciega Bay (Hutton *et al*, 1956). Distribution includes Gulf States and Mexico (Abbott, 1954). OS 5.57-33.17‰; OT 16.5-31.4°C.

Family Cerithiidae

Cerithium floridanum Morch

Florida Cerith

Several specimens collected from grassy beds in Boca Ciega Bay during October. Common in shallow waters throughout Tampa Bay. Specimens varied in size from 30.5 to 36.9 mm. Reported from similar habitat in Florida Bay, Florida but at a wider salinity range (32-47‰) by Tabb and Manning (1961). Occurs from North Carolina to southern half of Florida (Abbott, 1954). OS 31.33-32.48‰; OT 23.5-23.9°C.

Family Siliquaridae

Vermicularia sp.

Worm-shell

One specimen collected during October in Boca Ciega Bay. OS 32.48‰; OT 23.5°C.

Subclass OPISTHOBRANCHIA

Order ONCHIDIATA

Family Aplysiidae

Aplysia spp.

Sea-hare

Found throughout the most of study area and during entire period of observation. Four hundred and sixteen specimens collected during survey. Noted in largest numbers from October through March in Boca Ciega Bay. Eighty-two percent of collected *Aplysia* taken at water temperatures ranging from 15 to 25°C. OS 27.09-35.05‰; OT 13.5-32.1°C.

Bursatella leachi plei Rang

Ragged Sea-hare

Several specimens collected in Boca Ciega Bay during October and February. Observed at a wider salinity range in Oyster Bay, Florida (Tabb

and Manning, 1961). Distribution encompasses west and northwest Florida and the West Indies (Abbott, 1954). OS 32.05-32.41‰; OT 18.6-28.0°C

Class CEPHALOPODA

Family Loliginidae

Lolliguncula brevis (Blainville)

Brief Squid

One thousand six hundred eighty-four specimens collected. Numerically the second most abundant invertebrate found. Mantle length varied from 8.0 to 107 mm. Old Tampa Bay, the upper portion of Tampa Bay and Hillsborough Bay were the most productive sub areas for this species. None collected at the mouth of Tampa Bay or adjacent coastal waters. Maximum trawl catches observed during late summer and early fall. Ninety per cent of specimens immature. Reported from Florida Bay, Florida (Tabb and Manning, 1961). Geographic distribution extends from Maryland to Florida and the Gulf of Mexico; the Caribbean Sea, and the Atlantic coast of South America to Rio de Plata (Voss, 1956).

On the basis of squid collections in this survey, a study of certain biological, ecological, and economic aspects of this mollusk was conducted by the authors (Dragovich and Kelly, 1963). OS 17.32-35.66‰; OT 12.6-32.0°C.

Family Octopodidae

Octopus sp.

Two juveniles collected during August and May in Boca Ciega Bay and Tampa Bay. OS 34.87‰; OT 24.4°C.

Phylum ECHINODERMATA

Class ASTEROIDEA

Family Astropectinidae

Astropecten articulatus (Say)

Frequently observed on sandy bottom in central portion of Tampa Bay. Observed distribution extended from central portion of Tampa Bay seawardly. The arm length of collected specimens varied from 9.3 to 80 mm. Found from the Carolinas to northern Uruguay (Tortonese, 1956). OS 25.70-35.93‰; OT 15.3-29.6°C.

Family Luidiidae

Luidia clathrata (Say)

Occurred only on sandy bottom in Boca Ciega Bay, Tampa Bay, and immediate offshore waters. Present throughout entire sampling period. Arm length of collected specimens varied from 13 to 134 mm. Previously reported from Boca Ciega Bay by Hutton *et al* (1956). Occurs from New Jersey to Florida, the West Indies, and Brazil (Miner, 1950). OS 26.4-35.93‰; OT 14.7-30.7°C.

Family Echinasteridae

Echinaster spinulosus Verill

Taken only in Boca Ciega Bay and at Egmont Key. Primarily collected from sandy bottom having some vegetation. Occurred throughout sampling period. Arm length of collected specimens varied from 9.0 to 36.0 mm. Observed in Whitewater Bay, Florida at a lower salinity range (22-29‰) than recorded here (Tabb and Manning, 1961). Previously reported from Boca Ciega Bay (Hutton *et al*, 1956). Found from Florida to Cape Hatteras (Pratt, 1948). OS 31.73-35.61‰; OT 15.2-31.0°C.

Class OPHIUROIDEA

Order OPHIURAE

Family Amphiuridae

Ophiophragmus wurdemani (Lyman)

One specimen collected during January in Boca Ciega Bay. Arm length and disc diameter were 196 mm. and 12 mm., respectively. Range extends from North Carolina to Mississippi (Thomas, 1962), coastal waters of northern Gulf of Mexico (Priddy *et al*, 1956), and west coast of Florida (Thomas, 1961). OS 31.55‰; OT 16.52°C.

Family Ophiotrichidae

Ophiothrix angulata (Say)

Four specimens collected during October in grass beds off Egmont Key. Reported from Boca Ciega Bay (Hutton *et al*, 1956), and Florida Bay, Florida (Tabb and Manning, 1961). Mainly a southern species occurring from Chesapeake Bay to the West Indies and Rio de Janeiro (Miner, 1950). OS 33.84‰; OT 25.5°C.

Family Ophiidermatidae

Ophioderma brevispinum (Say)

Several specimens collected during February and March from grassy bottom in Boca Ciega Bay. Arm length and disc diameter of collected specimens varied from 15 to 37 mm and from 8 to 12 mm, respectively. Abundant in collections from Boca Ciega Bay by Hutton *et al* (1956). Our observed salinity range generally agrees with range observed in Florida Bay Florida (Tabb and Manning, 1961). Found from Massachusetts to Florida, Gulf of Mexico, and Caribbean area (Ziesenhenné, 1955). OS 33.08-34.16‰; OT 15.2-19.0°C.

Family Ophiolepididae

Ophiolepis elegans Lütken

Several specimens with disc diameter up to 16 mm taken during February and November from sandy bottom in Boca Ciega Bay. Reported here also by Hutton *et al* (1956). Extremely abundant on sandy bottom off

east Cape Sable, Florida (Tabb and Manning, 1961). Occurs from Carolinas to the West Indies in 2 to 20 fathoms of water (Miner, 1950). OS 33.51‰; OT 20.4-23.3°C.

Class *ECHINOIDEA*

Family Toxopneustidae

Lytechinus variegatus (Lamarck)

Common in *Thalassia* and *Gracilaria* flats at Egmont Key and Terra Ceia Bay throughout the sampling period. Occasionally observed in Tampa Bay. Absent in Old Tampa and Hillsborough Bays. Disc diameters ranged from 12 to 93 mm. Reported from Boca Ciega Bay by Hutton *et al.* (1956). Range extends from North Carolina to the West Indies, and Brazil; found in Bermuda (Miner, 1950). OS 26.76-35.61‰; OT 14.2-29.5°C.

Family Scutellidae

Mellita quinquiesperforata (Leske)

Very common on sand bottom in Tampa Bay and immediately adjacent offshore waters. Absent in collections from Old Tampa, Hillsborough, Boca Ciega, and Terra Ceia Bays. Disc diameters varied from 15 to 118 mm. Reported from Boca Ciega Bay by Hutton *et al.* (1956). Scarce in shallow waters from Vineyard Sound to Cape Hatteras to the West Indies (Miner, 1950). OS 28.37-35.93‰; OT 15.2-30.5°C.

Encope michelini L. Agassiz

Single specimen collected three and one-half miles offshore. Found in Gulf of Mexico from Yucatan to Florida (Mortensen, 1948).

Class *HOLOTHUROIDEA*

Family Cucumariidae

Pentacta pygmaea (Theel)

Twenty-three specimens, 17.5 to 67.5 mm in length, collected in Boca Ciega Bay and at Egmont Key during January, February, March, June, July, October and December. Appears to prefer sandy bottom with some vegetation. Common in Florida waters (Clark, 1933). OS 30.81-35.61‰; OT 16.5-31.4°C.

Phylum *CHORDATA*

Class *ASCIDIACEA*

Family Synoicidae

Amaroucium pellucidum Leidy

Pink Sea Pork

Rarely collected during this study. Observed during April and September in Boca Ciega Bay and near Egmont Key. Often washed ashore on beaches off St. Petersburg Beach. Range extends from Buzzards Bay Massachusetts to Tortugas and west coast of Florida (Van Name, 1945). OS 33.26-33.75‰; OT 20.2-28.0°C.

Family Styelidae

Styela plicata (Lesueur)

Occurred from October through March in Boca Ciega Bay and off Longmont Key. Occasionally observed in Old Tampa, Tampa, and Terra Ceia Bays. Much more common than the preceding species. Primarily found on sandy bottom with some vegetation. Length of 148 specimens varied from 12 to 78 mm. Widely distributed on the coasts of warmer parts of the Atlantic, Pacific, and Indian Oceans, including the Mediterranean, but not recorded from the west coast of America (Van Name, 1945). OS 27.70-34.20‰; OT 15.3-30.8°C.

Family Molgulidae

Molgula spp.

Most numerous organisms in our trawls. Over 6,000 specimens collected during survey. Occurred from October through June. Particularly numerous on muddy and sandy bottom intermingled with vegetation. Observed in largest numbers at mouth of Alafia River. Diameter of collected specimens varied from 5 to 55 mm. No species identification made during early months of survey. *M. manhattensis* (De Kay) and *M. occidentalis* Traustedt were identified to species during midpoint of survey. *M. occidentalis* occurs from North Carolina to West Indies; *M. manhattensis* extends from Portland, Maine to Louisiana, and northeastern Texas (Van Name, 1945). OS 18.12-35.53‰; OT 14.1-29.6°C.

DISCUSSION

Biological collections revealed 78 genera, 82 species (4 subspecies), and 2 unclassified groups of invertebrates. Ninety-two per cent of the invertebrates were benthic. The remaining 8 per cent were pelagic consisting of portunid crabs, squid, and sea slugs.

A close taxonomic affinity was noted between the fauna in Tampa Bay and the Carolinian fauna of the North American Atlantic Coast. Seventy-two species were common to both Tampa Bay and the Atlantic Coast. Six species are found only on the west coast of Florida. *Dysidea fragilis*, *Cliona celata*, *Siphonosoma cumanense*, and *Styela plicata* are known for their world-wide distribution. *Halichondria bowerbanki* and *Libinia dubia* are found on both sides of the Atlantic Ocean.

The number of species found in Tampa Bay is relatively small compared with 254 species observed in Florida Bay by Tabb and Manning (1961). Forty-three genera, 43 species, and 2 subspecies found in Tampa Bay were also observed in Florida Bay. The difference in species diversity observed during this study and that by Tabb and Manning may be partially attributable to the difference in methods of collection. Tabb and Manning collected their specimens with a 12-foot otter trawl, a van Veen bottom grab, small-mesh seines, fish toxicants, traps, night-light dipnetting, chan-

TABLE 1

DISTRIBUTION OF THE PRINCIPAL INVERTEBRATES OF THE TAMPA BAY AREA
IN RELATION TO BOTTOM TYPE

Organisms	Bottom Type						Total
	S	SV	MSV	SM	M	MV	
Number of Organisms							
<i>Molgula</i> spp.	0	2,385	258	197	4,288	0	7,128
<i>Lolliguncula brevis</i>	284	413	215	302	427	43	1,684
<i>Penaeus duorarum</i>	0	314	879	28	127	39	1,387
Juvenile Portunidae	19	469	207	71	49	44	859
<i>Callinectes sapidus</i>	30	111	184	37	140	58	560
<i>Lytechinus variegatus</i>	0	419	1	0	0	0	420
<i>Neopanope texana texana</i>	21	282	65	12	35	2	417
<i>Aplysia</i> spp.	19	334	56	0	7	0	416
<i>Pagurus longicarpus</i>	7	83	47	28	17	0	182
<i>Libinia dubia</i>	3	123	19	1	10	0	156
<i>Styela plicata</i>	1	117	30	0	0	0	148
<i>Mellita</i>							
<i>quinquesperforata</i>	130	0	5	0	0	0	135
<i>Melongenella corona</i>	0	6	69	0	4	27	106
<i>Echinaster spinulosus</i>	0	75	1	0	0	0	76
<i>Metoporphaphis calcarata</i>	11	35	4	0	1	0	51
<i>Astropecten articulatus</i>	19	19	6	0	0	0	44
<i>Luidia clathrata</i>	26	7	7	0	0	0	40
<i>Pagurus pollicaris</i>							
<i>floridanus</i>	9	22	2	4	2	0	39
Total	579	5,219	2,055	680	5,107	213	13,848
Total without <i>Molgula</i> spp.	579	2,834	1,797	483	819	213	6,720
S = sand SM = sand-mud							
SV = sand with vegetation M = mud							
MSV = mud-sand with vegetation MV = mud with vegetation							

nel nets, push nets, and by hand picking. All of our collections were made with a ten-foot shrimp try-net and a beach seine.

Hutton *et al* (1955) recorded 44 genera and 57 species in Boca Ciega Bay. In their collections, mollusks were represented by 43 genera, 48 species and 1 subspecies, and echinoderms by 8 species. Only 1 species of arthropod was recorded. None of the sponges, annulates, arthropods or ascidians observed during the present study were recorded by those authors. All species of echinoderms and 10 species of mollusks collected by them were also observed in our study.

The decapod fauna of Tampa Bay is similar to that of Alligator Harbor, Florida. Of 36 decapods observed during our survey, 33 were also noted by Wass (1955) in Alligator Harbor.

TABLE 2
DISTRIBUTION OF INVERTEBRATES BY REGIONS IN TAMPA BAY AREA

	Throughout Tampa Bay Estuary and offshore	Hillsborough Bay and Old Tampa Bay	Tampa Bay and adjacent Gulf waters	Exclusively adjacent Gulf waters
Porifera			<i>Dysidea fragilis</i> <i>Halichondria bowerbanki</i> <i>Cliona celata</i>	
Annulata	<i>Nereis</i> sp.		<i>Siphonosoma cumanense</i>	
Arthropoda	<i>Penaeus duorarum</i>	<i>Squilla empusa</i>	<i>Sicyonia typica</i>	<i>Petrolisthes</i> <i>galathinus</i> <i>Dromidia</i> <i>anillensis</i> <i>Calappa</i> <i>flammea</i> <i>Portunus</i> <i>spinimanus</i> <i>Arenaeus</i> <i>cribrarius</i> <i>Hexapanopeus</i> <i>angustifrons</i> <i>Hepatus</i> <i>epheliticus</i>
	<i>Trachypenaeus constrictus</i>	<i>Upogebia affinis</i>	<i>Trachypenaeus similis</i>	
	Caridean shrimp	<i>Persephona punctata</i>	<i>Petrolisthes armatus</i>	
	<i>Pagurus longicarpus</i>	<i>Eurypanopeus</i> sp.	<i>Emerita talpoida</i>	
	Juvenile Portunidae	<i>Eurypanopeus depressus</i>	<i>Pagurus pollicaris floridanus</i>	
	<i>Portunus gibbesii</i>	<i>Panopeus herbstii</i>	<i>Petrochirus diogenes</i>	
	<i>Callinectes sapidus</i>	<i>Uca rapax</i>	<i>Hypoconcha arcuata</i>	
	<i>Neopanope texana texana</i>		<i>Limulus polyphemus</i>	
	<i>Neopanope packardii</i>		<i>Heterocrypta granulata</i>	
	<i>Menippe mercenaria</i>		<i>Pitho anisodon</i>	
	<i>Libinia dubia</i>		<i>Pilumnus sayi</i>	
	<i>Metoporphaphis calcarata</i>		<i>Podochela riisei</i>	

Mollusca

Melongena corona
Nassarius vibex
Aplysia spp.
Lolliguncula brevis

Polinices duplicatus
Anadara transversa
Macoma tenta
Mulinia lateralis
Crassostrea virginica

Bulla occidentalis

Anachis avara
Prunum apicinum
Batillaria minima
Murex pomum
Echinochama cornuta

Bursatella leachi
plei

Octopus sp.
Laevicardium mortoni
Aequipecten irradians
Aequipecten i. concentricus
Urosalpinx perrugata
Martesia striata
Brachidontes exustus
Barbatia candida
Chione cancellata

Chione intapurpurea

Echinodermata

Oliva sayana
Cerithium floridanum
Vermicularia sp.
Astropecten articulatus
Luidia clathrata
Echinaster spinulosus

Ophiolepis elegans
Lytechinus variegatus
Mellita

Ophiophragmus wurdemanni
Ophiotrix angulata
Ophioderma brevispinum

quinquiesperforata
Encope michelini
Pentacta pygmaea

Styela plicata
Molgula occidentalis
Molgula manhattensis

Amaroucium pellucidum

Urochordata

A close association between the animal communities and the type of bottom which they inhabit has been recognized by modern ecologists (Thorson, 1957). Although in our investigation no study of the substratum was made, the bottom over which trawls were made consisted of several different types, (Table 1). The distribution of 18 most numerous taxa in relation to bottom type disclosed that the densest aggregations were over sandy bottom associated with vegetation. This is particularly noticeable when *Molgula* spp. are excluded from the total count. All arthropods, *Stomatopoda variegatus*, *Aplysia* spp., *Styela plicata*, *Echinaster spinulosus*, and *Lolliguncula brevis*, comprising 72 per cent of the dominant taxa, were most abundant in the dense aggregation of turtle grass, eel grass, and *Gracilaria* spp. *Molgula* spp., *Melongena corona*, *Calinectes sapidus*, and *Lolliguncula brevis* were found in large numbers over a muddy bottom. *Urosalpinx quinquiesperforata*, *Luidia clathrata*, and *Astropecten articulatus* were characteristic organisms for sandy bottom. The scarcity of the remaining species on sandy bottom suggests poor sand epifauna.

The areal species diversity in Tampa Bay and adjacent offshore waters displayed a distinguishable pattern (Table 2). Exceedingly higher species diversity was noted in the waters of Tampa Bay and immediately offshore than in the brackish waters of Old Tampa and Hillsborough Bays. In the latter instances, entire groups of animals, such as Porifera and Echinodermata, were completely absent. Echinoderms were well represented in Boca Grande Bay, the lower portion of Tampa Bay and in the offshore waters. Arthropods were the most widespread group of organisms encountered. Commercially important crustaceans, *Penaeus duorarum* and *Callinectes sapidus*, were widely distributed and were numerically the most prominent arthropods. The majority of molluscan species was also primarily confined to lower Tampa Bay and offshore waters. *Lolliguncula brevis* was the most abundant mollusk found during this study. The squid occurred with greatest frequency in brackish waters of Old Tampa Bay, Hillsborough Bay, and upper portions of Tampa Bay (Dragovich and Kelly, 1963). The scarcity of annulates in our collections may be ascribed to the types of sampling gear employed. *Molgula occidentalis* and *Molgula manhattensis* were the principal ascidians and the most numerous organisms found. *Molgula manhattensis* is known to live in highly polluted, low-salinity waters (Van Name, 1954). The potential utilization of these ascidians as indicators of pollution or changing hydrologic conditions is worthy of further exploration in our estuarine studies.

This survey of some ecological, biological and faunistic aspects of macro-invertebrates in Tampa Bay estuary has shown that *Molgula* spp., *Lolliguncula brevis*, *Penaeus duorarum*, *Callinectes sapidus*, and juvenile portunids were the most prominent representatives. The areal distribution

of macro-invertebrates and their relation to the bottom type of the survey area exhibited definite patterns. Further surveys with different collecting gear might show greater taxonomic diversity of the resident invertebrate

SUMARIO

OBSERVACIONES ECOLÓGICAS DE MACRO-INVERTEBRADOS EN LA BAHÍA DE TAMPA, FLORIDA, 1961-1962

Las observaciones recogidas en este reporte fueron hechas en relación con un estudio ecológico de la Bahía de Tampa, Florida, y aguas adyacentes. En la lista de especies se incluyen datos ecológicos referentes a los distintos macroinvertebrados. En el año comprendido entre Agosto de 1961 y Agosto de 1962, 78 géneros y 82 especies de esponjas, anélidos, sipuncúlidos, crustáceos, decápodos, gasterópodos, pelecípodos, cefalópodos, equinodermos y ascidias fueron cogidos en la Bahía de Tampa. Este bajo estuario incluye: Bahía de la Vieja Tampa, Bahía de Hillborough, Bahía de Tampa, Bahía de Boca Ciega y Bahía de Terra Ceja y tiene un área de 346 millas cuadradas y una costa de 212 millas. Los sedimentos del fondo están formados por una mezcla de cuarzo terrígeno y carbonato de origen biológico. El lodo fino está distribuido en las cabezas de la bahía y localizado en depresiones en el fondo de la misma y los sedimentos más gruesos son encontrados en canales. Los lechos de yerbas, marinas, son extensos y están presentes muchas especies de algas. El clima en esta área es húmedo y subtropical, con un promedio de lluvia anual de 49 pulgadas, con una temperatura atmosférica media máxima y mínima de 27.1°C y 17.6°C. La temperatura del agua está íntimamente asociada con la temperatura del aire y alcanza un máximo de 32°C en Julio o Agosto y un mínimo de 10°C en Diciembre o Enero. Durante el verano y principios del otoño, las variaciones de temperatura generalmente no exceden 1°C. La lluvia y aguas que corren son las responsables de los cambios estacionales en la salinidad.

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FEEDING BY THREE SPECIES OF FISHES ON THE EGGS OF SPAWNING ALEWIVES.—Predation on fish eggs by fishes is common. Price (1963, *Bull. Ohio Biol. Sur., new series* 2(1):1-89), for example, found fish eggs in the stomachs of 5 of the 10 species of Lake Erie fishes he examined. Recently, Wells and Beeton (1963, *Trans. Am. Fish. Soc.* 92(3):245-255) have shown that fish eggs are a regular item in the diet of the Lake Michigan bloater (*Corerogonus hoyi*). Although food studies have revealed that fish eggs are frequently eaten by fishes, the eggs found during these studies usually are not identified as to species and the circumstances under which the eggs were ingested are also usually unknown. Observations on aggregations of fishes attending the spawning acts of Great Lakes alewives (*Alosa pseudoharengus*) provided the opportunity to document the circumstances surrounding a case of egg predation and to describe the behavior of the fishes involved. A sample of the attendant aggregations and of the spawning alewives permitted positive identification of the species preying on eggs and made it possible to determine the extent to which each species, including the spawners, ingested eggs.

Great Lakes alewives regularly undertake spawning migrations into rivers tributary to southern Lake Michigan. Alewives are exceedingly abundant in the spring and early summer in the Kalamazoo River, which enters southern Lake Michigan near Saugatuck, Michigan. Catches as large as 5,000 pounds in a single 10-min drag have been made by commercial trawl fishermen at this time in the lower reaches of the river. Spawning alewives can be seen regularly during June and July from the dock of the Bureau of Commercial Fisheries Research Vessel Base on the Kalamazoo River in Saugatuck, about 2 miles above the river mouth. This dock, from which the observations to be described were made, extends into the river about 80 ft, is 60 ft wide, and is faced with interlocking sheet-steel piling. Water depth is 10 ft at the end of the dock. The river is approximately 325 ft wide at this point and the current is light (1-2 mph).

The spawning act of alewives involves two or more fish which swim rapidly with

sides touching in a tight circle 8-12 in. in diameter, spiraling upward from the depths (the limit of vision is about 1½ ft in the turbid river water) to the surface. The act terminates after 1 or 2 circles have been completed at the surface; the spawners then swim rapidly downward and out of sight. Casual observation of alewives spawning at the foot of the dock at 5:00 PM on 24 June 1963 revealed that aggregations of fishes consisting of minnows and small alewives were attendant on the spawning acts. Immediately following the termination of a spawning act and while the spawners could still be seen swimming downward, an estimated 50-100 minnows and several small alewives rushed into the area of spawning where they milled about excitedly as though feeding. The excitement and milling usually subsided within 5 sec and, unless spawning occurred again in the same or an immediately adjacent area within about 10 sec, the aggregation of minnows and small alewives also dispersed downward and out of sight. When spawning took place repeatedly at short time intervals in the same area (within 10 to 15 sec and 5 to 6 ft), the number of fish in the aggregation increased and the aggregation remained in view near the surface between spawnings.

In addition to the initial observation at 5:00 PM on 24 June, observations were made also at 6:00, 7:00, 8:00, 8:30, and 10:30 PM on the 24th, and at 2:00 and 7:00 AM on the 25th. Observations during darkness (10:30 PM and 2:00 AM) were made with the aid of a flashlight. Alewife spawning was confined almost exclusively to the area within 1 or 2 ft of the end of the dock at 5:00 and 7:00 PM and at 7:00 AM. Up to four separate, simultaneous spawning acts were observed along the 60 ft of the end of the dock at those times. Spawning became more frequent at the end of the dock as well as at greater distances from the dock at 8:00, 8:30, and 10:30 PM. As many as six separate, simultaneous spawning acts were counted along the end of the dock at 8:00 PM. At 2:00 AM, when spawning intensity reached a diurnal peak, the activity which could be heard clearly (termination of the spawning act involves considerable splashing) seemed to be distributed evenly over the entire surface of the river. Spawning

near the end of the dock was reduced considerably at that time; no simultaneous spawning acts were detected.

Aggregations of fishes were present at every spawning act observed at the foot of the dock during daylight and were also seen with spawners on two occasions at 7:00 AM (when light was ideal for observation) at a distance of about 20 ft from the end of the dock. Observations during darkness (10:30 PM and 2:00 AM) failed to disclose any aggregations accompanying spawners near the dock. It is not known whether the absence of aggregations near the dock during darkness indicates that the aggregations had moved where they could not be observed, or that members of the aggregations had discontinued their apparent predation. Evidence that spottail shiners, *Notropis hudsonius* (which made up the bulk of the aggregations), feed only sparingly after dark has been given by Price (1963).

A single drag of a minnow seine through an area of intensive spawning activity at the end of the dock at 7:00 PM captured 524 spottail shiners, 2 emerald shiners (*Notropis atherinoides*), and 60 alewives. All alewives and emerald shiners and a subsample of 211 of the spottail shiners were preserved for later examination. Total lengths (tip of the snout to the tip of the tail, lobes compressed) were taken from the preserved fish. The length distribution of the spottail shiners had two well-defined modes. The first mode contained 199 fish 2.5 to 3.6 in. long (average 3.0 in.); the 12 fish in the second mode were 3.7 to 4.4 in. long and averaged 4.0 in. Stomachs were examined from 36 fish 2.5 to 3.4 in. long (average 3.0 in.) in the first mode and from 7 fish 3.7 to 4.4 in. long (average 4.0 in.) in the second. The length distribution of alewives also was bimodal. The first mode contained 13 fish 2.8 to 4.6 in. long (average 3.8 in.) and the second had 47 fish 5.2 to 8.1 in. long (average 6.6 in.). Stomachs of all alewives in the first mode and 27 in the second mode were studied. The lengths of the latter fish ranged from 5.2 to 8.1 in. and averaged 6.7 in. All of the alewives in the smaller group were sexually immature and all of the 27 examined from the larger group were nearly ripe or ripe. The two emerald shiners were 4.4 and 4.8 in. long.

Thirty-four of the 36 spottail shiners in the 2.5- to 3.4-in. length range had eaten

alewife eggs (up to 125 in one 3.0-in. specimen) as had 3 of the 7 individuals in the 3.7- to 4.4-in. length range (up to 15 eggs in one 4.4-in. specimen). One of the smaller and 4 of the larger individuals had empty stomachs. Shiner scales (almost certainly spottail shiner scales) were found in the stomachs of 14 of the smaller and 4 of the larger individuals. Twelve of the 13 alewives in the 2.8- to 4.6-in. length range had eaten alewife eggs (up to 440 in one 4.0-in. fish) as had 8 of the 27 alewives in the 5.2- to 8.1-in. length range (up to 20 in one 5.5-in. specimen). None of the alewives examined had empty stomachs. Seven of the smaller and 26 of the larger had ingested shiner scales. The larger alewives had taken many more scales than had the smaller alewives and the stomachs of several of the larger alewives were tightly packed with scales. One of the emerald shiners captured had eaten 21 alewife eggs and several shiner scales; the stomach of the other was empty.

Although larger spottail shiners and alewives (and possibly larger emerald shiners) may feed only lightly on alewife eggs, small spottail shiners and alewives appear to be very effective egg consumers. No small emerald shiners were taken, but they are known to have been abundant in the lower reaches of the Grand River (at Grand Haven, Michigan) in 1960, where alewives spawn (author's observation); they, too may be important consumers of eggs of alewives.

The presence of large numbers of shiner scales in the stomachs of many of the fish is not fully understood. The scales of spottail shiners are highly deciduous and it is probable that many would be lost during the vigorous activity associated with their feeding behavior described above. Although it is possible that the fish may have picked up some of the scales accidentally (while irrigating their gills or attempting to ingest other items), the large number of scales in the stomachs of certain fish seems to indicate that many may have been ingested deliberately. Ernest Karvelis of this laboratory has advised me that scales of the closely related shad (*Alosa sapidissima*) impaled on a single hook are an effective angling lure for shad on their spawning grounds.—THOMAS A. EDSALL, U. S. Bureau of Commercial Fisheries, Biological Laboratory, Ann Arbor, Michigan.

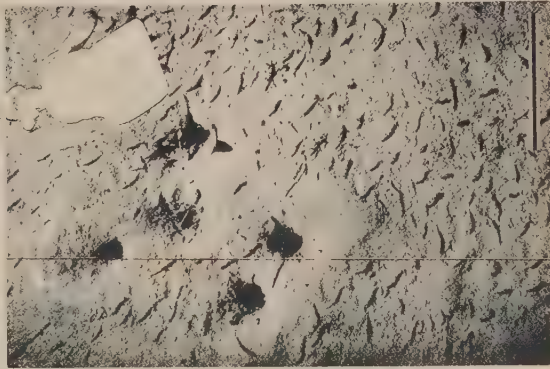
Camera

and

Bottom-Grab

The identification of animals shown on bottom photographs has been a problem. A new system makes it possible to satisfy reluctant biologists.

By K. O. Emery and A. S. Merrill



Station 1234, southeast of Nova Scotia ($43^{\circ}10'.6$ N.; $65^{\circ}00'.0$ W.) in 168 m. Brownish-green silty clay; sample contains 143 animals weighing 11.8 grams. Only polychaete worm tubes (probably Maldanidae) plus several large burrow holes can be seen in the photo.

photographs of the sea bottom have been made but experience has shown that they are easier to make than to interpret, particularly for biological purposes. Most biologists are reluctant to identify animals and plants from photographs; they prefer to have the specimens at hand. Thus, the biologist cannot fully exploit the many existing photographs for distribution or ecological relationships. Several thousand large bottom samples have been obtained with dredges and grabs during the same period; however, the great distance between existing photographs and samples, coupled with the known patchy distributions of organisms, prevent the combining of data from specimens and photographs. Even when care is taken, photographs and samples cannot be taken reliably at the same spot on separate lowerings from anchored ships and certainly not from hove-to ships.

This difficulty has been solved by combining a bottom sampler as a source of specimens and a camera to view ecological relationships at the same site. The sampler is essentially a clamshell grab whose open jaws span an area of 0.56 m^2 . A trip line below the grab activates the camera and light unit when the device has been lowered to about one meter above the bottom. After the film is exposed the grab continues downward to retrieve a large (as much as 0.2 m^3) sample of the same or essentially the same material which was photographed.

The original camera-grab was developed in 1961 by R. J. Menzies, L. Smith, and K. O. Emery at the University of Southern California using a Hasselblad camera and a flash bulb within a 250-kg (empty) grab designed and built by A. Campbell and used on the University's research vessel since 1964. At Woods Hole the device has been modified by D. M. Owen through substitution of a 35-mm Robot camera and a small stroboscopic light source. The area of bottom photographed is 0.48 m², 72% of which is between the jaws of the grab.

260 paired photographs and samples were obtained during 1963 aboard the R/V 'Gosnold' as part of a joint program between the Institution, the U.S. Geological Survey and the Bureau of Commercial Fisheries to investigate the continental shelf and slope off the United States east coast. Most of the lowerings have been off New England where bottom materials range from boulders through gravel and sand to clay. At least 80 per cent of the photographs are of excellent quality. Most of the pictures are black-and-white exposures but some are in color. The photographs on these pages were selected with the aid of R. L. Wigley and R. B. Theroux as examples of the different types of bottom materials and of the kinds of animals that inhabit such bottoms. Scale is indicated by a bar representing 10 cm on the sea bottom.

Bottom materials in the samples correspond closely to the descriptions, with the exception that some bottoms consist of sand, silt, or clay smoothly covering gravel or boulders which are dug out and retrieved by the heavy grab. There is also a general correspondence of epifauna (surface life) in samples and photographs, but, of course, most of the organisms living in the sediment, the infauna, remain concealed. At some stations organisms too small to be seen in the photographs are the main constituent in the grab both in

DR. EMERY, geologist on our staff since 1962, is in charge of the cooperative program in geology maintained in the field by the Bureau of Commercial Fisheries at Woods Hole, specializes in shellfish ecology and systematics.

terms of numbers and of weight. Certain small amphipods and foraminifera are good examples; for instance, from station 1323 there was obtained an estimated one-third million foraminifera weighing 19.8 grams, and the total number of all other animals was 169 weighing only 14.2 grams.

Animal behavior

It is evident that geologists can make use of photographs which show animals that live only on particular kinds of bottom. Plotting the distribution of these species is tantamount to plotting known bottom types. Examples are the sand dollar, Echinarrhynchus, which lives on or slightly buried in sand, and the brittle star, Ophiura, which is restricted to silts and clays. Biologists can find such photograph-sample pairs useful for studying the behavior as well as the distribution of identified organisms. Two instances are illustrated by the accompanying photographs. The photograph at station 1061 reveals an association between the sea anemone and caridean shrimp. At station 1275 an instantaneous reaction of a sea scallop occurred when the trip weight struck nearby, but no such reaction is apparent at station 1052 where the organism is an anemone.

By 1966 we expect to have a total of about 1500 photograph-sample pairs on a 18-km grid throughout the entire continental shelf and slope between Key West and Nova Scotia. Study of these pairs should provide considerable new information in marine biology and marine geology.

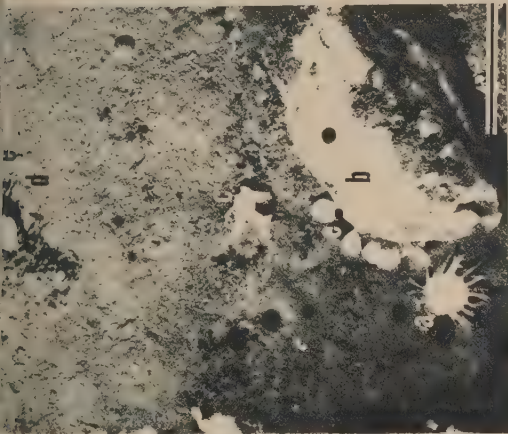
*See also: Schellema, R. S., "Deep Sea Biological Dredging", Vol. X, No. 2, and special issue on photography, Vol. VI, No. 1.



Station 1052, east of Cape Cod (42°10'0"N; 69°13'5"W.) in 200 m. Brown sand; sample contains 24 animals weighing 1.4 grams. Several tube dwelling coelenterates, Cerianthus, have their tentacles expanded naturally. Note to the right of the anemone the trip weight the tube remains of a dead specimen of Cerianthus.



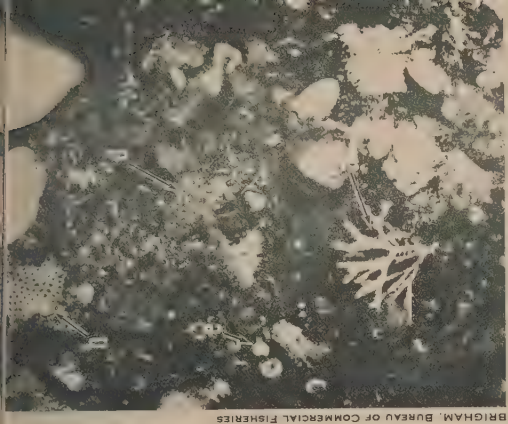
Station 1061, southeast of Cape Cod ($40^{\circ}11'0''\text{N}$, $68^{\circ}29'5''\text{W}$.) in 507 m. Green-black Sticky clay, gray sand, a few angular pabbles (probably glacial till); sample contains 29 animals weighing 4.1 grams. Photo shows clearly two large sea anemones, Balanus. Neatly camouflaged are several (a) caridean shrimp (Decapoda) facing outward from the anemones.



Station 1235, southeast of Nova Scotia ($43^{\circ}10'4''\text{N}$; $65^{\circ}15'3''\text{W}$.) in 144 m. Gravel and boulders to 35 cm partly buried by silty clay; sample contains 153 animals weighing 62.4 grams. Bottom photo shows: (a) sea anemone, Ceriantthus, (b) low flat sponge colony, Porifera, (c) sea anemone, Actinaria, (d) branching bryozoan, Tubulipora, (e) brachiopod, Terebratulina. Holes made by burrowing animals also are evident.



Station 1323, 40 km south of Hudson Submarine Canyon off New Jersey ($39^{\circ}20'3''\text{N}$; $72^{\circ}29'5''\text{W}$.) in 139 m. Greenish-gray fine grained poorly sorted slightly-silty sand; sample contains 169 animals weighing 14.2 grams. Note the following: (a) starfish, Astropecten, (b) sea pen, Pannatulacea, (c) heart urchin tests, Brissus, (d) holes probably made by sedentary polychaete worms.



Close-up of faunal assemblage on a rock obtained in sample from Station 1235 (see bottom photo from same station). Photo was made in the laboratory after the animals had been preserved: (a) branching bryozoan, Tubulipora, (b) encrusting bryozoan, (c) brachiopods, Terebratulina, (d) gelatinous sponge, (e) serpulid polychaete worm, Spirorbis. (Photo is about $1\frac{1}{2}$ times actual size)



Station 1275, south of Montauk Point, Long Island, New York ($40^{\circ}40'2''\text{N}$; $71^{\circ}45'5''\text{W}$.) in 59 m. Gravelly medium-grained brown sand; sample contains 116 animals weighing 53.4 grams. The sea scallop, Placopetean, disturbed by the lead trip weight snapped its valves together so quickly that water forced from it, stirred up sand on the bottom. Note arrow of compass which is embedded in the lead weight.

ICHTHYOLOGICAL NOTES

RELATIONSHIP BETWEEN ACTIVITY AND BLOOD COMPOSITION IN CERTAIN MARINE TELEOSTS.—The blood composition of fishes has been related to their ecological niche by various investigators. In general, both the size and numbers of erythrocytes and the level of hemoglobin are highly correlated with the activity of both freshwater and marine fishes (Hall and Gray 1929, *J. Biol. Chem.* 81: 50; Saito 1954, *Bull. Jap. Soc. Sci. Fish.* 19: 144; Smith, Lewis, and Kaplan 1952, *Prog. Fish-Cult.* 14:169; Haws and Goodnight 1952, *Physiol. Zool.* 35:8). Gray (1953, *Biol. Bull.* 107:219) demonstrated a positive correlation between the gill surface area and activity of fish. Pelagic species had more lamellae per millimeter of gill filament and a larger gill area per gram of body weight than did the benthic forms. Vernberg and Gray (1953, *Biol. Bull.* 104:445) found also that the brain homogenates of active fishes had a higher respiratory rate than the more sluggish fishes. Since physiological activity has been related to fishes in benthic and pelagic habitats, we have compared the blood characteristics of indigenous benthic and pelagic fishes to determine if there is a relationship between fishes from these habitats and the cellular components of the blood.

Determinations made on the blood samples included erythrocyte counts, hematocrits, and hemoglobin values. Leucocyte and thrombocyte counts also were made for some species. The following 7 species of

adult fishes were used in these determinations: toadfish, *Opsanus tau*; flounder, *Paralichthys* sp.; Atlantic croaker, *Micropogon undulatus*; striped bass, *Roccus saxatilis*; bluefish, *Pomatomus saltatrix*; king mackerel, *Scomberomorus cavalla*; and Spanish mackerel, *Scomberomorus maculatus*.

Blood samples were collected from the fish in the laboratory and in the field. In the laboratory, blood samples were obtained from fish narcotized with tricane methanesulfonate, M.S.-222 (Tech. Bull., M.S.-222-Sandoz, The Anesthetic of Choice in Work with Cold Blooded Animals, Sandoz Pharmaceuticals, Hanover, N. J.), which facilitated handling of the fish. Since the mackerels could not be brought back to the laboratory alive, the blood samples were obtained at sea, without the benefit of M.S.-222. Preliminary results indicate that blood samples taken from the active fishes in the laboratory were not different from blood samples taken at sea.

The kidney-puncture technique of Boroughs and Reid (1957, *Anat. Rec.* 128: 524) was used for the collection of all blood samples. Hypodermic syringes used were flushed with aqueous heparin to prolong the coagulation time of the blood. The blood sample was then placed in a 10-ml beaker coated with a mixture of dried ammonium and potassium oxalate. The oxalate mixture prevented blood clotting for several days. Analyses were completed within 24 hr of blood collection.

Three solutions were tested for the dilu-

TABLE 1. COMPARISON OF BLOOD CHARACTERISTICS FOR 7 SPECIES OF TELEOSTS.

Species	Hematocrit Percent of Volume		Hemoglobin Grams Percent		Erythrocytes × 10 ⁶ Cells/mm ³		Thrombocytes × 10 ⁴ Cells/mm ³		
	Range	$\bar{x}$	Range	$\bar{x}$	Range	$\bar{x}$	Range	$\bar{x}$	<i>n</i>
Benthic									
<i>Opsanus tau</i>	23.0–33.7	27.50	5.3– 7.1	6.21	0.61–0.84	0.68	10.0–40.0	23.50	10
<i>Paralichthys</i> sp.	25.5–37.0	29.25	5.6– 7.9	6.64	2.22–3.86	2.91	—	—	10
<i>Micropogon undulatus</i>	18.0–39.8	29.00	4.7– 9.8	7.30	1.69–4.90	3.33	12.0–32.0	20.30	30
Pelagic									
<i>Roccus saxatilis</i>	36.0–41.3	38.70	8.6–10.4	9.50	3.42–4.53	3.95	—	—	5
<i>Pomatomus saltatrix</i>	29.0–57.0	43.35	7.0–15.4	10.40	3.12–5.63	4.21	0.0–21.0	10.27	34
<i>Scomberomorus cavalla</i>	32.0–43.0	36.30	7.3–10.3	9.30	2.66–4.59	3.54	—	—	6
<i>Scomberomorus maculatus</i>	26.5–48.0	38.80	7.6–12.2	10.40	3.15–6.13	4.54	—	—	58

tion of fish blood for cell enumeration: isotonic saline; Rees and Eckert's formula suggested by Slicher (1961, *Bull. Bingham Oceanogr. Coll.* 17:3); and Shaw's dilution fluids (1931, *J. Path. Bact.* 33:833). The Rees and Eckert's formula was chosen since the diluted sample could be used to count erythrocytes, leucocytes, and thrombocytes. All dilutions were made with red blood cell ratio pipettes; cell numbers were counted in a standard hemocytometer.

The hematocrit values were determined by the clinical microhematocrit method of Guest and Siler (1934, *J. Lab. Clin. Med.* 19:757) and recorded as percentage of volume. Capillary tubes 1-1½ mm in diameter coated with heparin were used in all determinations.

Hemoglobin content was measured according to the standard cyanmethemoglobin method. Using a Sahli pipette, 0.02 ml of anticoagulated blood was added to 5 ml of cyanmethemoglobin reagent with the hemoglobin content being determined colorimetrically at a wave length of 540 mμ. The hemoglobin value was expressed in grams per 100 ml of whole blood.

The erythrocyte counts, hemoglobin levels, and hematocrit values were higher for the pelagic species than for the benthic species (Table 1). The pelagic species, as typified by the bluefish, are highly active predaceous fishes requiring more oxygen than the less active benthic fishes, such as the toadfish. When pelagic and benthic fishes were compared as separate groups, it was demonstrated that the pelagic fishes had statistically significant larger numbers of erythrocytes and higher hemoglobin levels than the benthic fishes. However, there were significant interspecies differences in erythrocyte numbers within the groups. Even though there was an obvious difference between the mean hematocrit values for the pelagic and benthic fishes, no statistical comparisons were made since these values were in part influenced by the volumes of the blood cells.

Thrombocyte and leucocyte numbers did not show a correlation with the activity of the fish. Thrombocyte counts varied over a wide range. In some cases, such as the mackerels, thrombocytes were not detected. The range in leucocyte numbers was from 1,250 to 62,500 cells per cubic millimeter. Such great ranges in leucocyte numbers may be

the result of the routine handling of the fish. It has also been determined that fright can cause increases in the numbers of leucocytes.

Our results suggest a relationship between certain blood characteristics of fish and their respective ecological niche.—DAVID ENGEL AND EDNA M. DAVIS, U. S. Bureau of Commercial Fisheries, Radiobiological Laboratory, Beaufort, North Carolina.

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Shellfish Advisory Service — Cooperation With the Industry

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MOLLUSK SHELLFISH at the present time account for more than 12 per cent of the total landed value of our domestic commercial fisheries. In cold cash they represent about 45 million dollars. They are therefore of major importance to our United States fisheries economy and of direct concern to us. The Bureau of Commercial Fisheries which, in cooperation with the research and management agencies of the maritime states, is charged with the conservation and wise management of these important natural resources. While all of us should be, and no doubt are, consumers of this fine food, we should be vitally aware also of the significant place members of the shellfish industry, with their background of experience, have in this discussion. This makes a quartet of forces, state and federal research, state and industry management, that must work together in complete harmony to stabilize and increase production, to improve quality, to stimulate consumer demand, and as a result to develop and maintain a healthy shellfish industry.

These statements imply that there are conditions under par in this industry. This is unfortunately so. The list of problems is long and I shall not enumerate them at this time. Dr. J. L. McHugh, Assistant Director for Biological Research of the U.S. Bureau of Commercial Fisheries, in his speech entitled "Research and the Oyster Industry" told the members of the Oyster Growers and Dealers Association of North America that there is a large fund of knowledge available to draw upon, but generally unutilized by industry, state legislators, and some state management agencies.

This again is unfortunate. Therefore I should like to point out briefly and for background the historical picture of production of oysters and clams in the United States over the past 80 years. I draw once more on Dr. McHugh (1963) who illustrated this graphically in a prepared statement presented in public hearing to the Subcommittee on Fisheries and Conservation, Committee on Merchant Marine and Fisheries, U.S. House of Representatives.

Oyster Production

Oyster production on the Atlantic Coast in all sections has declined (Fig. 1). It is, however, the marked drop in the Chesapeake Bay yield that influences most seriously the total U.S. picture. The oyster culture in Maryland is still a relatively primitive one using antiquated tools and restrictive laws which

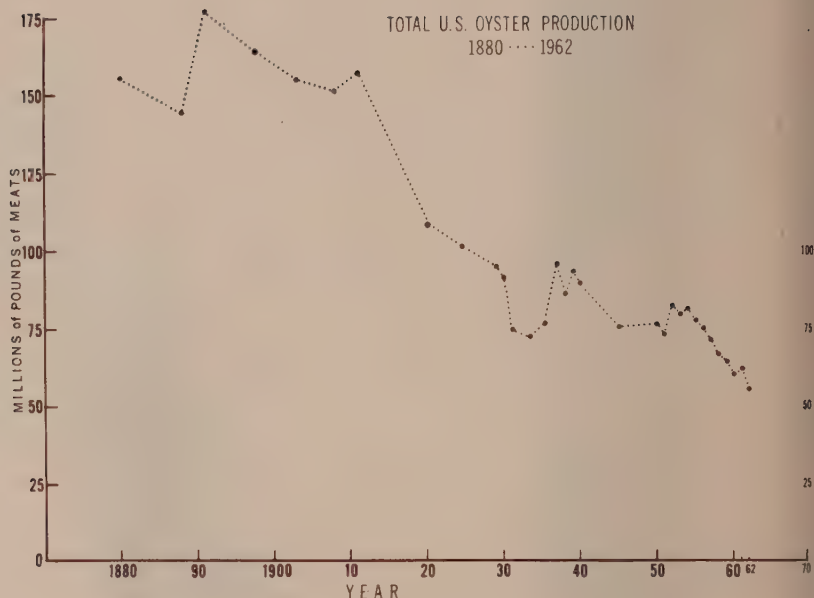


FIG. 1. Total U.S. oyster production 1880-1962.

limit modernization and expansion. In Virginia some progress has been made in improving culture methods, but restrictive legislation limiting expansion to submarginal areas compounds the problem of efficient cultivation and the control of predators and disease. In the states on the Gulf of Mexico production is low but relatively stable, although problems similar to those mentioned above exist here. On the Pacific Coast production has increased only after drastically altering the culture by importing seed from Japan on an annual basis. The local West Coast oyster, *Ostrea lurida* or Olympia, accounts for a small part only of this production. At one time eastern oysters, *Crassostrea virginica*, were shipped in car loads to the West Coast where they were simply held in storage in local waters. The eastern oyster did not respond in sufficient amount to any natural culture of seed in western waters. The practice of shipping fully grown oysters to the West Coast still is being done, but on a very limited scale, as one may easily realize after examining the curves of the decline of the Atlantic Coast oyster harvest. Oyster production regionally is summarized in Fig. 2.

Clam Production

Viewed as a whole, the clam industry in the United States appears to be in good condition, with a total annual production reaching 50 million pounds, as shown in Fig. 3. This figure, however, is derived from a number of different species and genera, all but one of which have shown a decline of considerable proportion. The surf or sea clam, *Spisula solidissima*, the fishery of which is primarily located off the New Jersey coast, has shown a phenomenal growth to offset the losses in production in the other clams. The soft clam, *Mya*

U.S. OYSTER PRODUCTION.....BY REGION

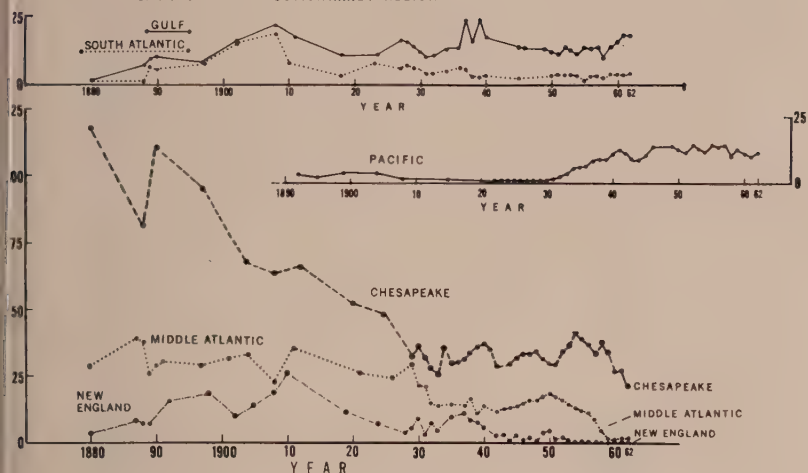


FIG. 2. U.S. oyster production . . . by region.

arenaria, in serious decline in the New England states, has been exploited heavily in Maryland over the past ten years. The soft clam harvest in Maryland for 1962 was 7 million pounds, which is an increase from practically nothing during this period. This spectacular production increase was made possible by an abundance of clams and by the recent invention of an escalator

TOTAL U.S. CLAM PRODUCTION 1889 1962

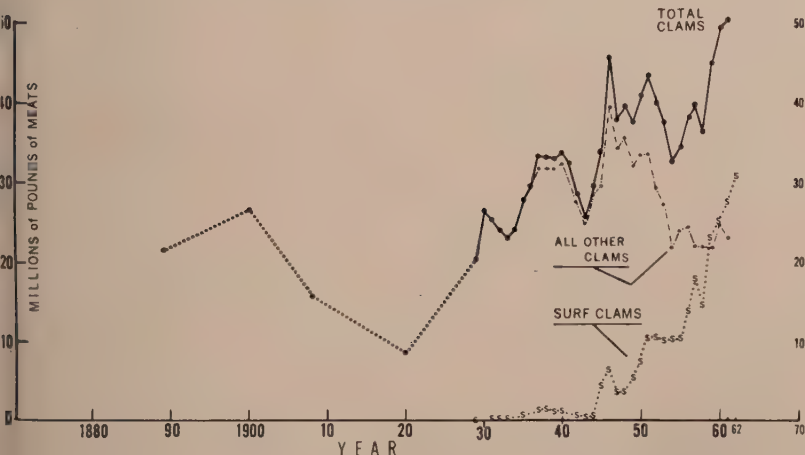


FIG. 3. Total U.S. clam production . . . 1889-1962.

clam dredge. Nevertheless, the Maryland production is limited by difficulty in marketing this newly exploited Chesapeake Bay resource.

Why Is Production Declining?

Production of oysters and clams, and perhaps scallops, is declining for many of the same reasons: predation by drills, crabs, fish, and starfish, among other predators; overfishing when the wild stock is not inventoried and managed within the sustainable yields; pollution and other human activities producing formidable complications to the maintenance of these important commercial shellfish resources; and unrealistic legislation which hampers the exercise of our most precious prerogative of free enterprise and healthy competition.

The Bureau of Commercial Fisheries is conducting research on many of these problems. State and university research laboratories also are studying these local adverse conditions. The shellfish industry in many areas is helping to solve some of its own ailments, mostly in the field of gear improvement. All this effort, however, is accumulating information in an isolated way. We know a great deal about many of these problems but we have not applied this knowledge effectively to general shellfish culture and management. Our methods of communication have not bridged the gap between knowledge and application. The Bureau of Commercial Fisheries has a legal responsibility for correcting some of this lapse. We have not done very much of this in the past except as the researchers attempt to pass their information back to the industry that needs it. This apparently has not been direct or positive enough to produce the desired improvements. The breakdown in communication has in part caused this enigma but steps are being taken to fill this need.

Shellfish Advisory Service

Dr. McHugh, in his speech to the Oyster Growers and Dealers Association in 1962, said that the Bureau was considering the organization of a Shellfish Extension Service. This service would work closely with industry, state scientists, and state administrators to interpret and utilize the scientific knowledge available, and to improve the basic knowledge on which to plan further improvements. Another task to be undertaken was the analysis of the shellfish laws that have outgrown their usefulness and actually hinder progress in management. In July, 1963, Dr. McHugh again addressed the same organization, but at this time he announced the installation of the Shellfish Advisory Service, generally following the plan proposed the previous year. He stated as he announced the new service that, "The shellfish industry has been profitable in the past and it still can be profitable if we put the combined knowledge and experience [of science and industry] to work".

He asked the question, "What are the principal requirements?" to make this work, and proposed the following: (1) a reliable supply of seed oysters developed to resist local ailments; (2) freedom from the vicissitudes of nature such as extremes of temperature and salinity, freshets, storms, siltation, disease, predators, and pests; (3) freedom from interference by man, such as over-exploitation, channel dredging, construction of dams and other barriers, filling of marshlands, pesticide spraying, water pollution, and the like.

There has been only token improvement, if any, in dealing with these principal problems of the shellfish industry, especially on the Atlantic Coast where major production has existed. In fact, space restrictions increase as pollution

growing areas expands. The laws requiring this are direct and necessary to protect human health. Other shellfish laws, however, impose restrictions that decrease the efficiency and increase the cost of a shellfish harvest. Something is lacking in the regulations and management programs when the decline in production persists. This and the lack of good communication between science and industry inhibits the progressive use of our accumulated knowledge. The U.S. Bureau of Commercial Fisheries' plan to meet this need is the installation of the Shellfish Advisory Service to help assemble the facts and consolidate them into a comprehensive program of cooperation to help rehabilitate the shellfish industry and change the direction of the current production curve.

Its staff will be expanded and service agents as they are available and trained will eventually be placed in the principal shellfish centers to aid and advise on area problems. Success of this experiment hinges on the extent to which cooperation develops among all responsible shellfish groups.

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Drift Bottle Experiment in the Northern North Pacific Ocean, 1962 - 1964*

Felix FAVORITE**

Abstract: During February and March 1962, drift bottles were released in groups of 120 in the north-central North Pacific Ocean along long. 175° W from the Aleutian Islands to lat. 41° N and along long. 155° W from the Alaska Peninsula to lat. 46° N, at each degree of latitude.

Eighty recoveries have been reported which range from the Bering Sea to as far south as northern California. Bottles released in area of dichothermal water, moved northward and westward around the Gulf of Alaska; those released south of this area but north of the Subarctic-Subtropic boundary at approximately lat. 42° N, drifted eastward to the Washington, Oregon, and California coasts. No recoveries have been reported from bottles released at lat. 41° N.

Future drift bottle studies are discouraged, but a line or lines of drifting, telemetry buoys is suggested.

1. Introduction

For decades, remnants of Japanese fishing equipment such as glass and cork floats, nets and flag poles have been recovered on the west coast of North America and considerable speculation has always arisen as to their specific point of origin. Recently HATA (1963) delineated four areas in the western North Pacific Ocean in which drift bottles had been released and subsequently recovered at specific locations: those released in area A were recovered on the North American coast north of lat. 50° N; those in area B on the North American coast between lats. 50° N and 40° N; those in area C, in the North Pacific south of lat. 40° N, and those in area D, on the east coast of Japan. He showed that bottles released in areas A and B drifted across the central Pacific in parallel paths at about lat. 43° N as far east as long. 145° W before being dispersed along the coast (Fig. 1). During the cruise of the MV *Bertha Ann* from February to April 1962 (FAVORITE, MORSE, HASELWOOD and PRESTON, 1964), we conducted a drift bottle experiment which provides additional information concerning the possible paths of floating objects in the central

Pacific.

Except for the drift bottle studies of DODI-MEAD and HOLLISTER (1958), most of the releases in the North Pacific have been of a random nature. The purpose of our experiment was to release drift bottles at closely spaced intervals normal to the general eastward flow in the Subarctic Region and determine if recovery locations were related to the water structure at the release locations, and to determine how far south objects could be released in this region and still be recovered on the North American coast.

2. Experiment

A total of 2,880 unballasted, short-necked bottles, 17 cm long and 4½ cm in diameter at the base, was released in groups of 120 at each degree of latitude from 55° to 46° N along long. 155° W and 51° to 41° N along long. 175° W. Additional groups of 120 bottles were released at lat. 51°30' N, long. 175°28' W; lat. 55°30' N, long. 155°W, and at lat. 41° N, long. 175° W. Lack of time at the end of the cruise prevented releasing bottles any further south at long. 155° W. The bottles, which contained only a data card with instructions and promise of a reward for return printed in Japanese, Russian, and English, were closed by a cork stopper and the tops dipped in melted paraffin wax. Although the bottles were pre-

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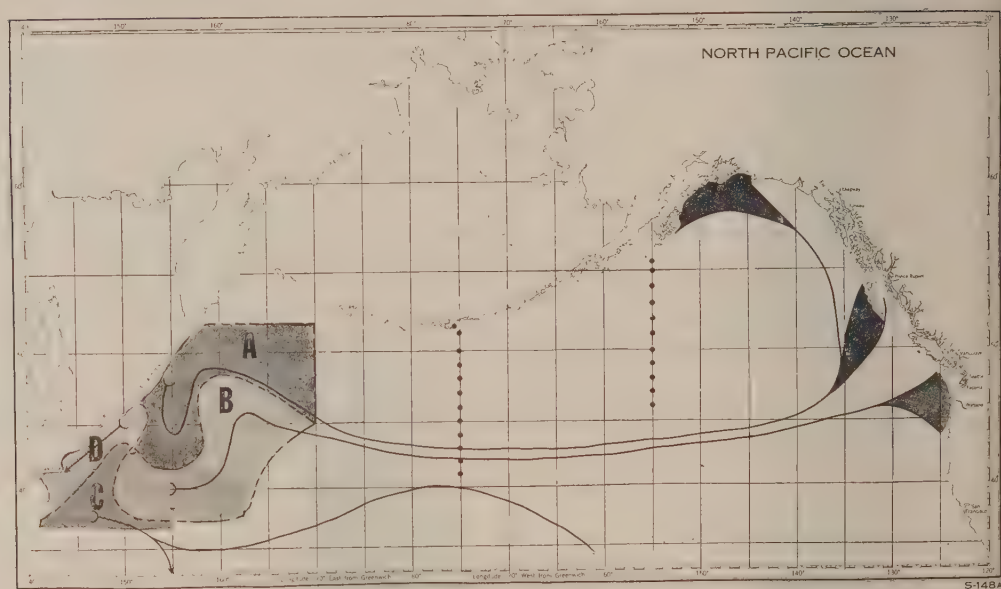


Fig 1. Areas of release and recovery, and approximate paths of drift bottles in North Pacific Ocean as shown by HATA (1963). Dots show locations of release of drift bottles during cruise of MV *Bertha Ann* during February and March 1962.

pared and placed in cardboard cases prior to the cruise, each bottle was individually identified at the time of release.

3. Results

The locations, or range of locations, at which

55 bottles released along long. 155°W were recovered are shown in Figure 2. The paths indicated are schematic and are based on, but do not conflict with the circulation pattern presented by DODIMEAD, FAVORITE and HIRANO (1963). Releases north of lat. 51°N were recovered

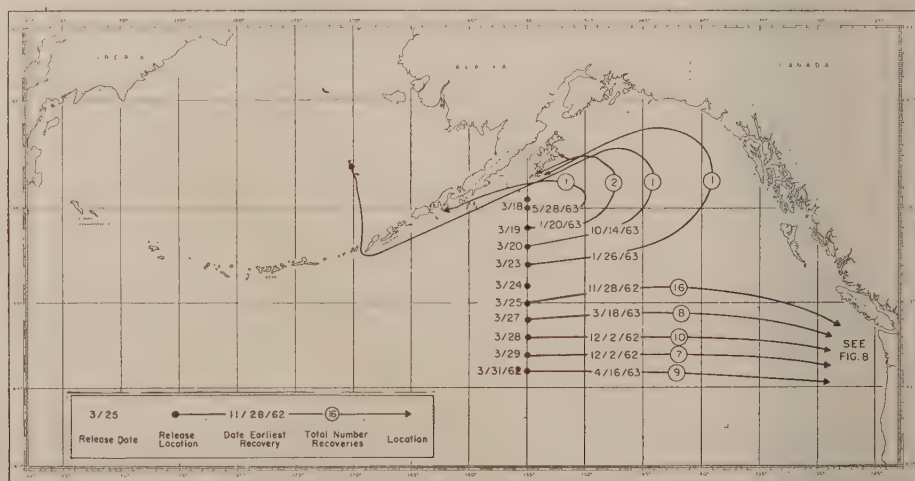


Fig. 2. Drift bottle experiment along long. 155°W.

the northern part of the Gulf of Alaska, the Alaska Peninsula and in the Bering Sea; those south of lat. 51° N were recovered from Vancouver Island to as far south as northern California. We have received no information from the bottles released at lats. 49° N or $55^{\circ} 30'$ N. The first nine recoveries were found on the coasts of Washington, Oregon and Vancouver Island during a 10-day period, November 28 to December 8, 1962. Of these, seven were released at lat. 50° N; one at lat. 48° N, and one at lat. 47° N (Fig. 3).

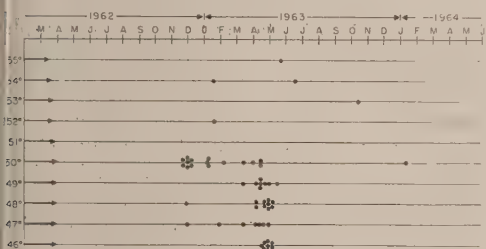


Fig. 3. Dates of recovery of drift bottles released along long. 155° W. (Arrows indicate date of release)

If we assume a hypothetical straight line path, the bottles traveled at a speed of approximately 6 miles per day. An unusually large number of returns from lats. 46° to 50° N occurred during April and the first part of May, but

subsequent to this period only a single recovery has been reported from bottles released at these locations.

Only 25 bottles have been recovered from releases along long. 175° W, but the general distributional pattern of recoveries is somewhat similar to that of releases along long. 155° W. Those released at lats. 47° to 49° N were recovered northward of Vancouver Island, and those released from lats. 46° to 42° N were recovered from Vancouver Island southward to Oregon (Fig. 4). No recoveries have been reported from releases northward of lat. 49° N or the release of 240 bottles at lat. 41° N. The first two recoveries reported were released at lat. 47° N and were found in Queen Charlotte Sound on January 25 and February 17, 1963; which indicates a drift of about 6 miles per day. Dates of recoveries shown in Figure 5 indicate a general relationship between the length of time before recovery and the distance north or south of the release location from lat. 47° N. Those released at lat. 42° N, were reported almost a year later than the initial recoveries from lat. 47° N.

4. Discussion

Limitations of drift bottle data are well known and have been adequately summarized

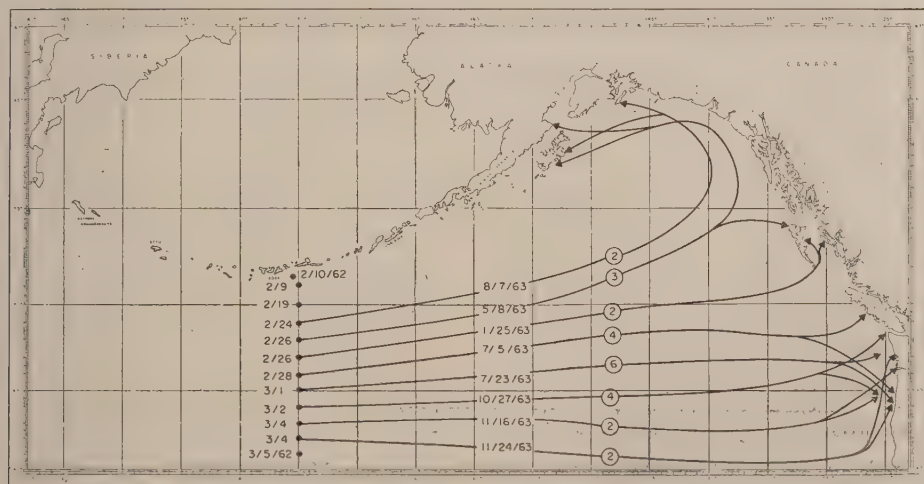


Fig. 4. Drift bottle experiment along long. 175° W.

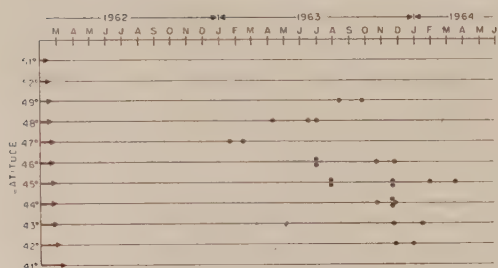


Fig. 5. Dates of recovery of drift bottles released along long. 175° W. (Arrows indicate date of release)

by WALDICHUK (1963) and others. Nevertheless, it is usually agreed that the bottles provide tangible evidence of circulation and a carefully planned experiment can contribute to our knowledge of surface circulation. In the analysis of drift bottle data, primary consideration must be given to the suitability of the recovery areas. Ideal conditions of a

straight, sandy coastline adjacent to a heavily populated area are most closely met along the Washington, Oregon, and California coasts and it is obvious that the majority of returns have been reported in this area. Although the British Columbia and Alaska coasts are irregular, rocky, and sparsely populated, sufficient recoveries have been reported to show the general features of circulation.

The pattern of recoveries along the North American coast from releases along long. 155° W and 175° W is quite similar to that reported by HATA from releases in the western Pacific. Although the available oceanographic station data are not adequate to determine surface circulation during the period the bottles were in the water, a relationship between the water structure existing at the time of release and the location of eventual recovery is evident and serves to strengthen Hata's premise of defining two discrete release areas on the basis

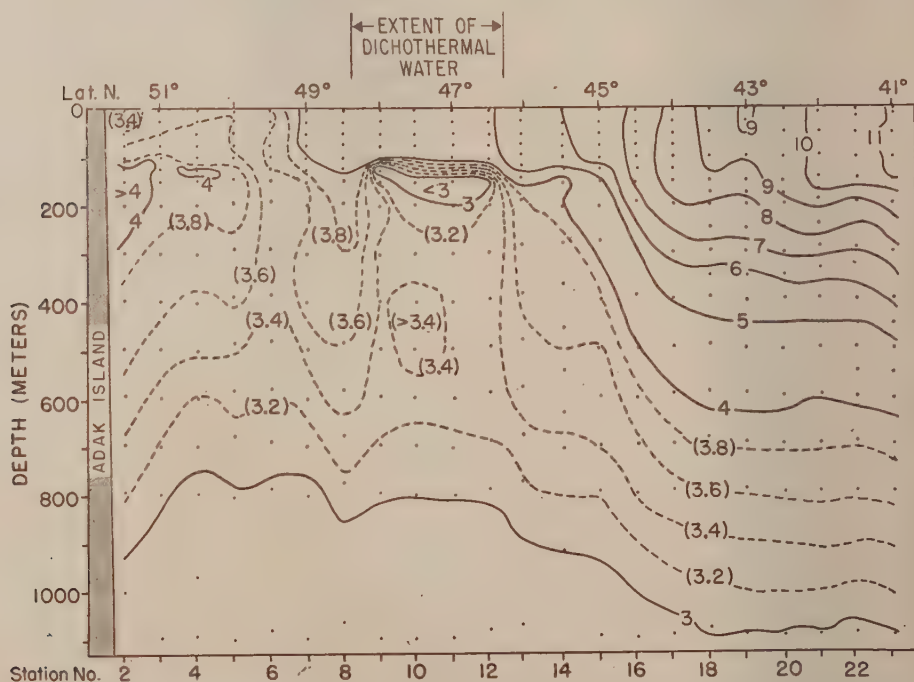


Fig. 6. Distribution of temperature in a vertical section along long. 175° W during February 1962, showing dichothermal water between lat. 46°30' N and lat. 48°30' N at 150 meters depth. (Contour interval 3° to 4°C-0.2°C; less than 3°C and greater than 4°C-1°C.)

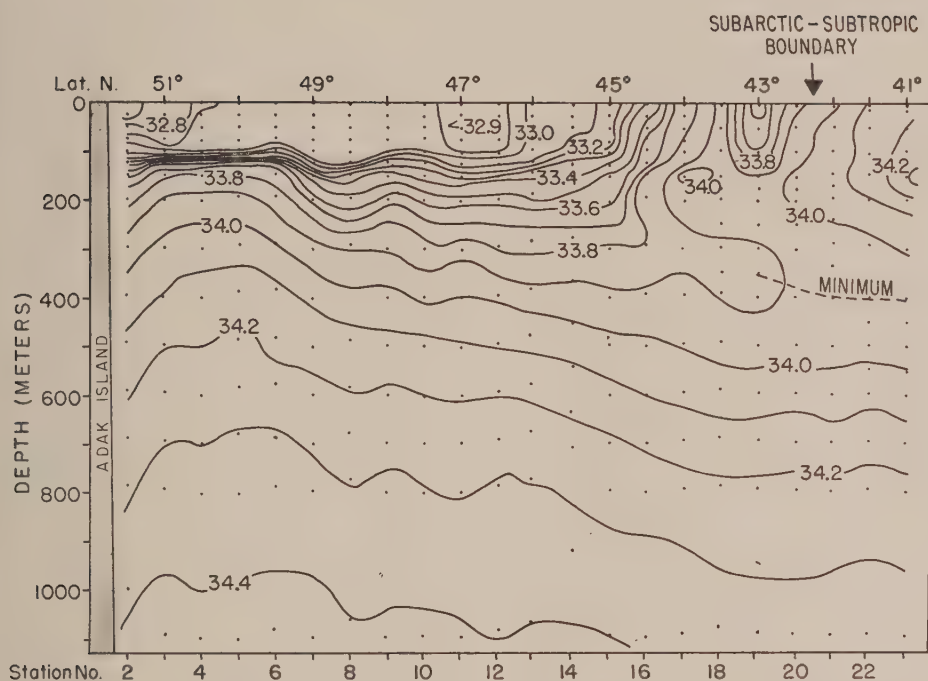


Fig. 7. Distribution of salinity in a vertical section along long. 175° W during February 1962—Subarctic-Subtropic boundary, determined by the vertical 34‰ isohaline, is indicated at lat. 42° N. (Contour interval 0.1‰ .)

of the recovery of drift bottles on the North American coast.

The vertical distribution of temperature which existed during the period the bottles were released along long. 175° W is shown in Figure 6. Clearly evident between lats. $48^{\circ} 30' \text{N}$ and $46^{\circ} 30' \text{N}$ at 150 meters depth is the temperature-minimum, dichothermal water, stratum characteristic of most of the Subarctic Region. Bottles released at the surface between lats. 47°N and 49°N were recovered in the Gulf of Alaska north of lat. 50°N . This recovery pattern is similar to that of releases from Hata's area A. The position of the Subarctic-Subtropic boundary in the central North Pacific, defined by DODIMEAD *et al.* as the latitude of the near-vertical 34‰ isohaline, occurred just south of lat. 42°N (Fig. 7). Bottles released in the transition zone, which existed between lats. 46°N and 42°N and is usually identified by having neither a tempera-

ture-minimum nor a salinity-minimum at depth, were recovered on the North American coast south of lat. 50°N in the same general location as bottles from Hata's area B. However, perhaps these relationships are only valid in the central and eastern North Pacific where the eastward flow is relatively zonal because Hata's separation of areas A and B does not conform to the well known distribution of dichothermal water in the western Pacific. Furthermore, between lats. 40° to 45°N and longs. 145° to 160°E the boundaries of areas A, B, and C are closely associated with the confluence of the Oyashio and Kuroshio systems, and it would be difficult to predict the eventual recovery location of drifting objects released in this area. For example, HATA shows two drift bottles which had been released on the west side of Japan and passed through the strait near Hakodate. One of these was recovered near Cape St. Elias, Alaska, which would in-

dicate passage through areas D and A; and the other was recovered in the Hawaiian Archipelago indicating passage through area D and C.

None of the bottles we released at lat. 41°N have been recovered, but their paths may be assumed to correspond to those of bottles from Hata's area C. Similarly, we can only speculate as to the eventual dispersal of bottles from locations north of lat. 49°N . Calculation of geostrophic currents along long. 175°W shows that these bottles were released in the westward flowing Alaskan Stream. We have shown that drift bottles released in this current either move southward and eventually eastward in the Subarctic Current and have been recovered on the North American coast approximately 18 months later (INPFC, 1960, p. 88), or move northward into the Bering Sea at longs. 175° to 170°E (FAVORITE, 1964). Because over 2 years have elapsed since the beginning of the experiment, it is assumed that these bottles have taken the latter course and will either pass through Bering Strait into the Arctic Ocean or, more likely, move around the counter-clockwise Bering Sea gyre, travel southward

along the Kamchatka coast, pass through area A off the Kurile Islands, and reach the North American coast during 1965.

This experiment also provides some insight into the nature of surface flow off the coast of Washington and Oregon. The almost simultaneous arrival of bottles from lats. 47° , 48° and 50°N , long. 155°W certainly suggests the possibility of a zonal, onshore movement. The absence of any recoveries in December 1962 from releases at lat. 49°N cannot be explained but it is interesting to note that at the end of April, when an unusually large number of recoveries were reported from releases at lats. 50° , 49° , 48° , 47° and 46°N , the distribution of recoveries along the Washington and Oregon coasts were quite similar (Fig. 8). Assuming all bottles were found as soon as they came ashore, and there is ample evidence that such is usually the case along these beaches, a rather long residence time is indicated for bottles in this coastal area during winter and early spring. One possible contributing cause is a well known reversal of flow off the Washington and Oregon coast in spring. REID (1959) has presented drift bottle evidence of a pronounced inshore



Fig. 8. Locations and dates of recovery of bottles released at indicated positions.

northward flow along the California, Oregon, and Washington coasts during winter; and the reversal of this flow in the spring, to the southward, is clearly documented by various studies on the plume of the Columbia River (BUDINGER, COACHMAN and BARNES, 1964). Thus the bottles could have been confined in the area off the Washington and Oregon coasts until the southward flow had been established. At that time, they would be first carried southward, and then, after passing Cape Mendocino (lat. $40^{\circ}25'N$) to seaward. This pattern would account for the abrupt termination of recoveries after this period, even though one bottle was recovered south of Cape Mendocino (Fig. 8d).

5. Conclusions

- 1) Drift bottles released along longs. 155° and $175^{\circ}W$ in the northern North Pacific Ocean south of the Alaskan Stream and north of the Subarctic-Subtropic boundary moved eastward, almost zonally, to the North American coast.
- 2) Those released in the area of dichothermal water were recovered on the North American coast north of lat. $50^{\circ}N$.
- 3) Those released in the transition area between dichothermal water and the Subarctic-Subtropic boundary were recovered south of lat. $50^{\circ}N$, and only one was found south of lat. $40^{\circ}N$.
- 4) None of those released south of the Subarctic-Subtropic boundary have been recovered.
- 5) Approximately 2 percent of the bottles have been recovered. This appears to be an average percentage of returns to be expected from an oceanic drift bottle experiment in the North Pacific.
- 6) The rate of drift of the early recoveries was approximately 5 miles per day. Maximum speeds in the Subarctic Current seem to occur at the southern edge of the dichothermal water.
- 7) The apparent zonal flow in the central and eastern part of the North Pacific Ocean suggests that considerable success might be achieved in predicting the general oceanic location of patches of water having a parti-

cular chemical or biological significance.

- 8) The rather uniform dispersal of bottles along the North American coast from oceanic locations having a considerable north-south extent, indicates that it would be very difficult to predict the effect of oceanic conditions on the coastal environment using data from less than an extensive network of stations.
- 9) The relatively consistent pattern of results from various Japanese, Canadian and United States' drift bottle studies in the northern North Pacific suggests that very little additional information can be obtained from such experiments except more detail on the specific features of local areas. To obtain more information on the oceanic system, a line or lines of drifting trans-Pacific telemetry buoys tracked by ships, shore stations, aircraft or satellites is required. Such a program would be enhanced by international cooperation, and this, at this time, appears to present no major problems.

Acknowledgments

The assistance of Miss Virginia COLEMAN, Miss Betty-Ann MORSE and Mr. Allen P. WIEGAND is gratefully acknowledged.

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OCEANOGRAPHY

By F. Favorite

The purpose of the oceanographic program is to investigate conditions and processes that occur in the salmon environment, and to determine which parameters affect the distribution and movements of species and stocks of salmon.

Oceanographic work during the past year was accomplished during four fishing cruises; and an experimental, independent oceanographic cruise was conducted off the coasts of Washington and British Columbia (Fig. 18).

Continual stormy weather was encountered during the November cruise of the MV *George B. Kelez* and only a few bathythermograph traces were obtained.

During winter, observations were made aboard the chartered MV *Bertha Ann* in the Bering Sea along longitudes 180° and 175°E. and south of the Aleutian Islands along longitude 180°; and aboard the *Kelez* southward of the Alaska Peninsula and in the Gulf of Alaska. Temperature profiles along longitudes 180° and 175°E. are shown in Figures 19 and 20. The lowest surface temperatures, 2.5°C., occurred at the northernmost fishing stations at both longitudes. This temperature is about 1°C. lower than surface temperatures found last winter south of Adak Island where salmon were also caught. Southward of the Aleutian Islands along longitude 180°, temperature conditions were quite similar to those encountered during winter 1962, and near the temperature front at latitude 45°N., the salmon catch was considerably reduced. Surface temperatures at the front, 6° to 7°C., were approximately 6°C. lower than maximum temperatures at which salmon have been caught in ocean areas during summer.

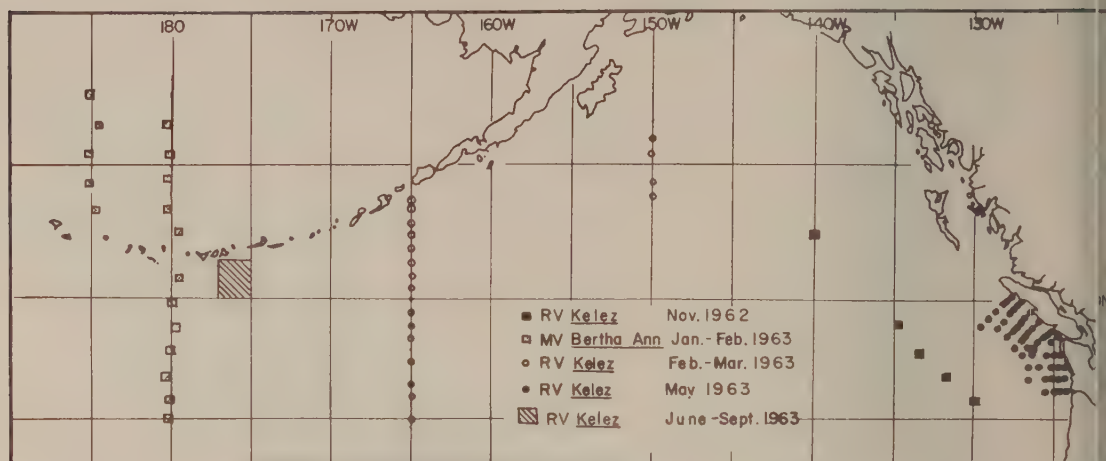


FIGURE 18. Oceanographic and bathythermograph stations, November 1962-September 1963.

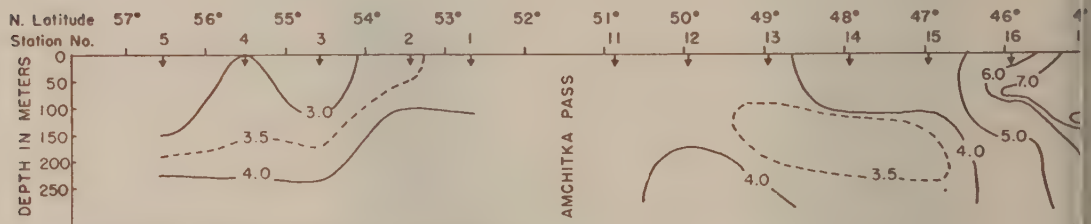


FIGURE 19. BT temperature profile along longitude 180°, January 28-February 22, 1963 (MV Bertha Ann).

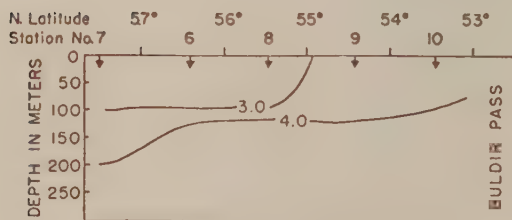


FIGURE 20. BT temperature profile along longitude 175°E., February 4-February 18, 1963 (MV Bertha Ann).

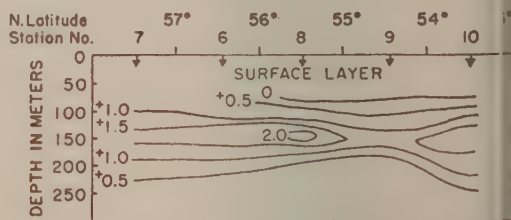


FIGURE 21. Difference in temperature (°C.) at station depths along 175°E. (data from MV Bertha Ann—1963 compared to MV Pioneer—1959).

The most significant feature of the temperature distributions was the increase in temperature of the stratum between 100 and 200 meters in the Bering Sea. Conditions in the stratum are removed from local seasonal influences, and have been relatively constant since at least 1949. Comparison of these 1963 data with observations obtained at similar locations by the MV *Pioneer* in 1959 is shown in Figure 21. The 1° to 2°C. increase in temperature at these depths is quite significant and is attributed to a northward intrusion of warm water from the Alaskan Stream south of the Aleutian Islands, and an accompanying retreat, either westward or northward, of cold water from the Kamchatka coast. However, it should be pointed out that bathythermograph readings are not as accurate as those obtained by reversing thermometers. Further analysis of this temperature anomaly will depend on whether or not other agencies have obtained additional data in this area.

The *Kelez* cruise south of the Alaska Peninsula provided an opportunity to determine if the conditions observed during the previous winter in the area were typical or anomalous, and hydrographic

The *Kelez* cruise south of the Alaska Peninsula provided an opportunity to determine if the conditions observed during the previous winter in the area were typical or anomalous, and hydrographic

1,000 meters were made¹. Comparison of vertical sections of temperature and salinity along longitude 155°W. during February 1963 with distributions of similar properties along longitudes 175°W. and 155°W. during February and March 1962 (see 1962 Annual report) showed that, although the temperature-minimum stratum was compressed latitudinally and displaced about 1° of latitude further north, the major features of water structure were similar. It is concluded that they are relatively persistent from year to year. The location of the temperature minimum was considered important because in early spring, as shown by INPFC research last year, it closely coincides with the distribution of sockeye salmon.

The fourth fishing cruise, the summer cruise of the *Gelez*, was designed to investigate changes in abundance of immature salmon southward of Adak Island, where large numbers of mature sockeye salmon quite suddenly appear during spring. These salmon are replaced in early summer by large numbers of immature salmon. The abundance of salmon in this area provides an excellent opportunity to seek out oceanographic parameters that may explain reasons for concentrations of salmon. Some results of this cruise will be discussed in detail.

The general assumption that the inshore area is a feeding ground has not been substantiated and, in some cases, the percentage of full stomachs in salmon caught by gillnets is higher in offshore areas. Further, it has been shown that in some instances plankton are more abundant offshore, away from the influence of the turbulent island passes. There are three current systems in the vicinity of Adak Island: north of the Island the flow is eastward toward Bristol Bay; south, the Alaskan Stream flows westward along the southern side of Aleutian Island arc; and immediately south of the Alaskan Stream, the Subarctic Current flows eastward toward the Gulf of Alaska. Because of the relatively uniform values of insolation in the Subarctic Region, surface temperatures are not a particularly useful property to identify specific surface water masses. Although, in spring and summer, turbulence and tidal mixing in the island passes effectively mix the warmed surface water downward resulting in lower temperatures in and near the passes than in the surrounding areas, this does not necessarily identify the water as originating either north or south of the islands. During summer, the water masses in current systems directly north and south of the islands

can be easily distinguished by the surface salinity; the former usually has a salinity characteristic of the oceanic part of the Bering Sea, 33.0 to 33.3‰, whereas the latter has a salinity of 32.4 to 32.6‰, which reflects the presence of dilute water of the Alaskan Stream which originates in the Gulf of Alaska. Unfortunately, as shown in previous reports, the Subarctic Current can only be recognized by properties at depth, and the boundary between the Alaskan Stream and Subarctic Current at the surface can be detected only by calculations or actual measurements of flow.

Although numerous north-south lines of stations were fished south of Adak Island during the summer (Fig. 22), only four will be discussed (Fig. 23), and these only in relation to sockeye salmon. The first line (Fig. 23), Station Nos. 3, 4 and 5, occurred during early July. Fifteen miles offshore no salmon were caught and from 15 to over 50 miles offshore the surface salinities were approximately 32.6‰. The first large catch, 357 sockeye salmon, occurred one week later at Station No. 11 (Fig. 23), 22 miles offshore where the surface salinity had increased to 33.2‰. Eight miles southward at Station No. 10, where the catch dropped to 161, the surface salinity was 32.5‰; and 30 miles further southward, where salinity was still about 32.5‰, only nine salmon were caught. Thus, the first large catch coincided with an intrusion of high salinity Bering Sea water and the subsequent formation of a salinity front about 25 miles offshore.

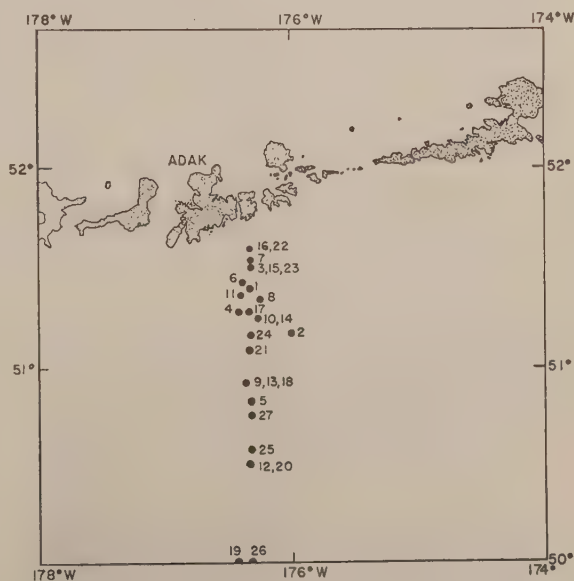


FIGURE 22. Oceanographic stations south of Adak Island, July 29–August 15, 1963 (MV *George B. Kelez*).

¹ Ingraham, W. James, Jr. North Pacific Oceanography February–March, 1963. U. S. Fish and Wildlife Service, Special Scientific Report—Fisheries (in press).

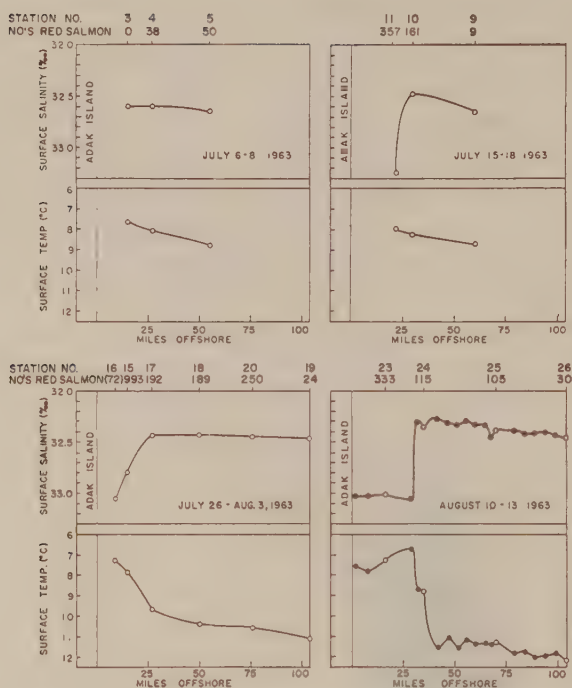


FIGURE 23. Surface salinity, surface temperature and sockeye salmon catches south of Adak Island, July 6-August 13, 1963 (MV *George B. Kelez*).

On July 26 (Fig. 23) the maximum catch of 993 sockeye salmon was made northward of the salinity front in water characteristic of the Bering Sea, and good catches of approximately 200 salmon were made south of the front to 75 miles offshore in water characteristic of the Alaskan Stream. Thus, it appears unlikely that salinity restricts the movement of salmon in this area. Calculations of geostrophic velocities, referred to 1,000 decibar level, show a westward flow (Alaskan Stream) between Station Nos. 16 and 20, and an eastward flow (Subarctic Current) southward of Station 20. This may account for the considerably reduced catch of only 24 salmon at Station 19 (southward of Station No. 20), even though the surface conditions were relatively similar to those at Station Nos. 17, 18 and 20. Further analysis of geostrophic velocities, which may provide some insight into the unusually high catches inshore, shows that at Station Nos. 16 and 15 the intrusion of high salinity water resulted in low velocities at the surface, but did not influence the appreciable westward velocity characteristic of this area at depth. In fact, at 50 meters the westward geostrophic velocity was approximately five times, and, at 200 meters, ten times the surface flow. Possibly this unusual condition of reduced flow at the surface provides a unique environment which confines

the salmon in this area near the surface and makes them more susceptible to capture in gillnets. Southward of Station 17 the velocities in the upper 100 meters are relatively uniform.

Surface observations were taken at close intervals during August 10-13 (Fig. 23) to more accurately determine the abruptness of the salinity front. It occurred about 30 miles offshore, and an unusually sharp gradient occurred within less than three miles. Also associated with this front was a 5°C. change in temperature.

Containment of the dilute water of the Alaskan Stream southward and well offshore of the Aleutian Islands adds to growing evidence that there is a continuous northward flow through all the Aleutian passes although there is no doubt of some northward movement through the deeper ones. The presence of large numbers of immature salmon in this area is justification for a more thorough look at the westward extent of the Alaskan Stream. In order to find the most complete observations one must go back to 1959 data.

In previous annual reports, we have suggested that the general extent of the Alaskan Stream could be delineated by the distributions of arbitrarily chosen properties ascribed to the system. A more accurate approach is through consideration of volume transport, which essentially are a measure of total flow in a column of water bounded by a grid of stations. Such a technique obviously requires closely spaced stations that permit determination of the boundaries of the system otherwise continuity cannot be assumed. Calculations of volume transport, referred to 1,000 meters, in the Alaskan Stream during the summer of 1959 showed a transport of 10×10^6 cubic meters per second (m^3/sec) westward along the Alaska Peninsula. As shown in Figure 24, $5.8 \times 10^6 m^3/sec.$, or one-half the transport, flowed westward at longitude $160^\circ W.$; the other $4.2 \times 10^6 m^3/sec.$ had recirculated in the Gulf of Alaska gyre. The main axis of the flow was westward south of the Aleutians with its gains to the north or south usually considered to be less than 25 per cent. A relatively constant transport of 4 to $6 \times 10^6 m^3/sec.$ extended as far west as longitude $170^\circ E.$, where the stream diverged at approximately latitude $51^\circ N.$ and sent about two-thirds of the transport northward into the Bering Sea and one-third southwestward into the western Pacific. The spacing of available oceanographic stations is not great to permit showing any further continuity in the system accurately. Having found the approximate magnitude of the flow, we can more confidently

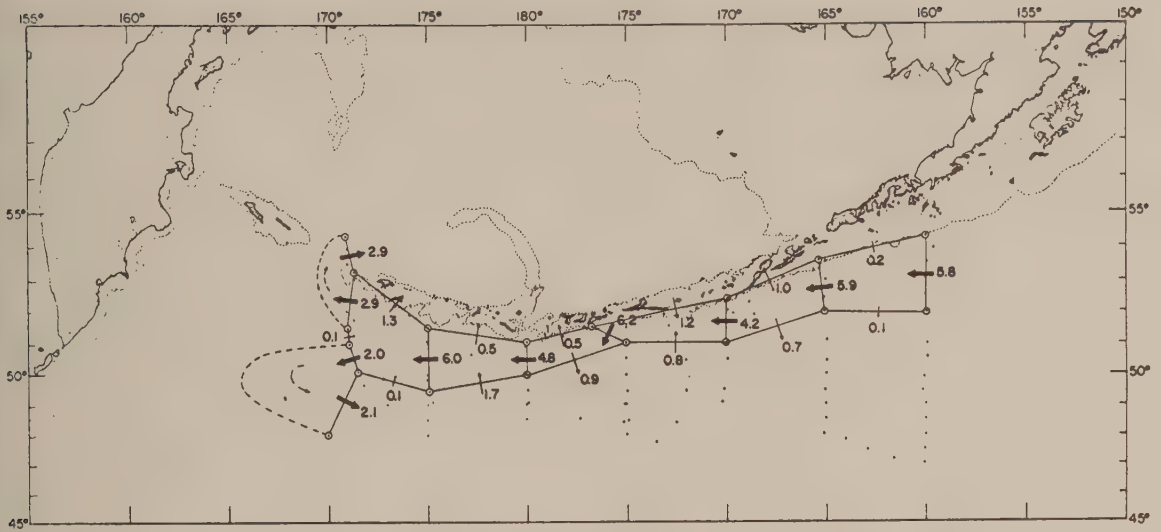


FIGURE 24. Volume transport ($10^6 \text{ m}^3/\text{sec}$) in Alaskan Stream, summer 1959. (Dots indicate station positions of MV *Pioneer*, MV *Tordenskjold* and *Oshoro Maru*.)

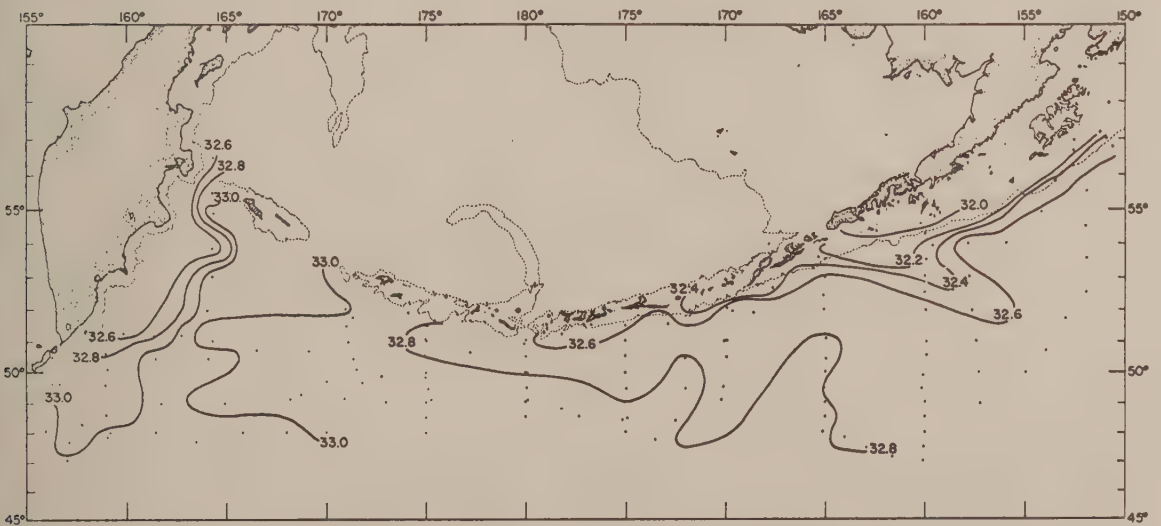


FIGURE 25. Surface salinity (‰), summer 1959. (Dots indicate station positions of MV *Pioneer*, MV *Tordenskjold*, HMCS *Oshawa* and *Oshoro Maru*.)

sider the evidence indicated by distribution of water properties. The distribution of salinity at 10 meters (Fig. 25) indicates recirculation at longitude 162°W . and a north-south salinity front at longitude 165°E . Mesothermal temperatures (Fig. 26) (i.e., maximum temperatures occurring below the depth of minimum temperature) are more enlightening. Good evidence is shown of the recirculation into the Gulf of Alaska at longitude 160°W . and of the divergence at longitude 170°E . At the latter location, the temperature

distribution shows a termination of the westward flow of the northern branch of the Alaskan Stream just westward of Attu, but the warm water associated with the southern branch continues westward to approximately longitude 165°E . at latitude 50°N .

This indicates that: (1) the northern branch of the Alaskan Stream does not continue across the Pacific to the Kamchatka coast but is blocked by an intrusion of cold water from the west and is forced to turn

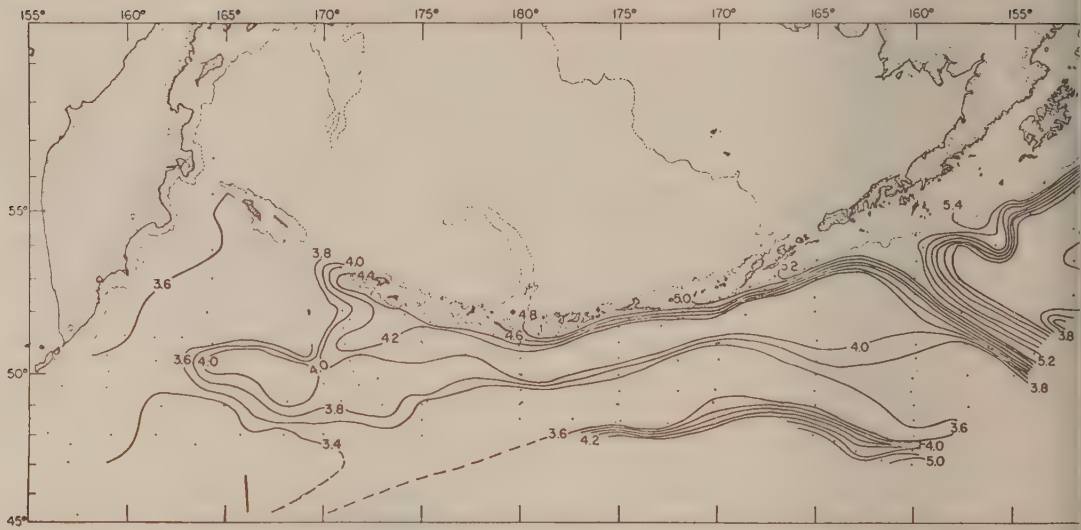


FIGURE 26. Mesothermal temperatures (C.), summer 1959.

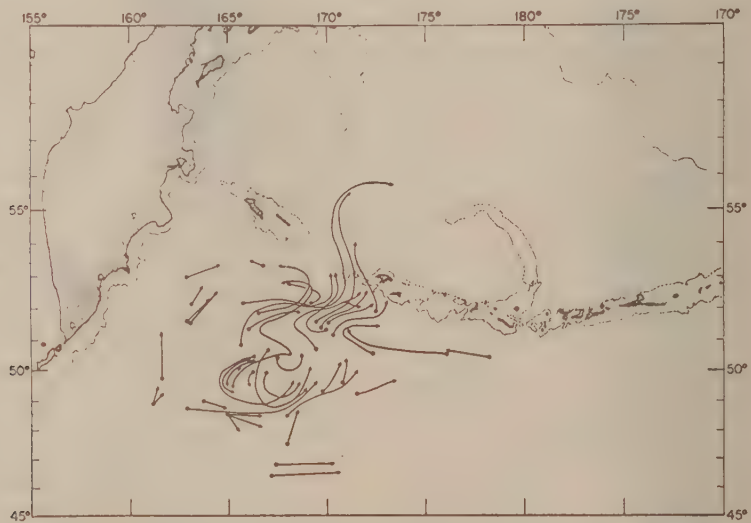


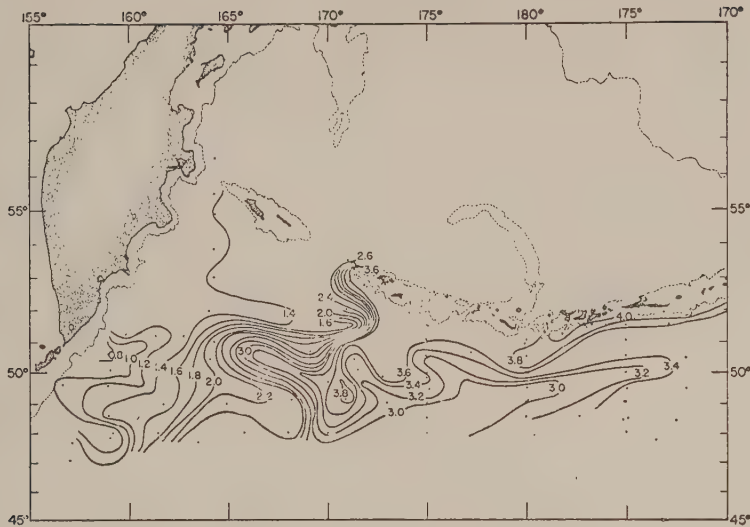
FIGURE 27. Release and recovery points of selected drift floats, spring and summer 1959 (adapted from Taguchi—see footnote).

northward in the vicinity of Attu Island and (2) the southern branch is also blocked in the vicinity of latitude 50°N. and longitude 165°E. and is forced to recirculate southeastward. These conclusions are considerably reinforced by additional evidence of release and recovery points of selected drift floats during spring and summer of 1959 as reported by Taguchi (1959)¹ (Fig. 27), and by the dichothermal

temperature distribution (Fig. 28). The 10°C. isotherm is based upon temperatures in the temperature minimum stratum which are influenced seasonally. This reflects a more immediate picture of surface circulation than the mesothermal temperature.

The general conclusion here is that adult mature salmon in the Aleutian area, if responding to surface or subsurface currents, can be expected to be found as far westward as latitude 50°N., longitude 165°E. during some period of their migration. Catch statistics published by INPFC show

¹ Taguchi, K. 1959. On the surface current in the mothership fishing ground based on the recovery of floats drifted (1959). Fisheries Agency of Japan, MS.

FIGURE 28. Dichothermal temperatures ($^{\circ}\text{C}.$), summer 1959.

salmon catches are made near this location each year.

We have reached the point in our oceanographic investigations where the gross features of the oceanic salmon environment have been determined and described and routine observations no longer substantially contribute to our present knowledge and understanding of conditions, or relationship to salmon. We have shown that unusual changes in salmon abundance were usually associated with a change in water properties, structure or flow. These conditions have been denoted by changes in temperature and salinity that have occurred between stations 30 to 60 miles apart along lines of stations over several hundred miles apart.

In order to increase our knowledge of environmental conditions, we need to investigate in greater detail the small scale phenomena in areas of known importance and complexity. This can be accomplished only by independent oceanographic cruises. We also require continuous observations of large scale phenomena, which can only be obtained by buoys.

Acquisition of the *George B. Kelez* has provided, for the first time, the capacity to conduct oceanographic investigations between the periods of fishing cruises, and our first such cruise was conducted off the Washington coast during May 1963 (see Fig. 18). Although at the 1962 Annual Meeting we proposed covering the area between latitudes 40° to $50^{\circ}\text{N}.$ and seaward to longitude $145^{\circ}\text{W}.$, absence of a comparable oceanographic coverage in the Gulf of Alaska considerably reduced the effectiveness of such a plan. In-

stead we completed an extensive pattern of inshore stations to determine the extent of the Coastal Domain and the nature of the front between coastal and offshore waters. Analyses of chemical nutrients and other trace elements were attempted, and new plankton capturing devices were tested.

This area of the North American coastline is unique in that the oceanic flow is directly onshore, particularly at the surface. There is also extensive onshore movement of salmon. As part of an experimental salmon cruise during winter 1962 aboard the *Bertha Ann*, drift bottles were released at 60-mile intervals southward of the Alaska Peninsula along longitudes $175^{\circ}\text{W}.$ and $155^{\circ}\text{W}.$ Recoveries to date are shown in Figure 29 (a and b). Bottles released between latitudes $46^{\circ}\text{N}.$ and $50^{\circ}\text{N}.$ were recovered on the Vancouver Island-Washington-Oregon-California coastline about eight months later. Bottles released northward of latitude $50^{\circ}\text{N}.$ circulated around the Gulf of Alaska. This separation of drift bottles closely resembles the separation of sockeye and pink salmon that occurred during early spring of 1962. Bottles released along longitude $175^{\circ}\text{W}.$ followed a similar pattern, except that bottles released as far south as latitude $47^{\circ}\text{N}.$ moved through the Gulf of Alaska gyre.

Studies in this general area between periods of fishing cruises will permit us to ascertain parameters that assist salmon in their homing migrations. The techniques proven effective and feasible aboard ship will be employed during the far ranging fishing cruises. Because conditions in this area will be altered by changes or fluctuation in the offshore environment

which are impractical to continuously monitor by ship, we hope to employ drifting telemetry buoys to record these changes. These buoys are the next

step in our long-range plans to provide pre of conditions in the Subarctic Pacific Ocean.

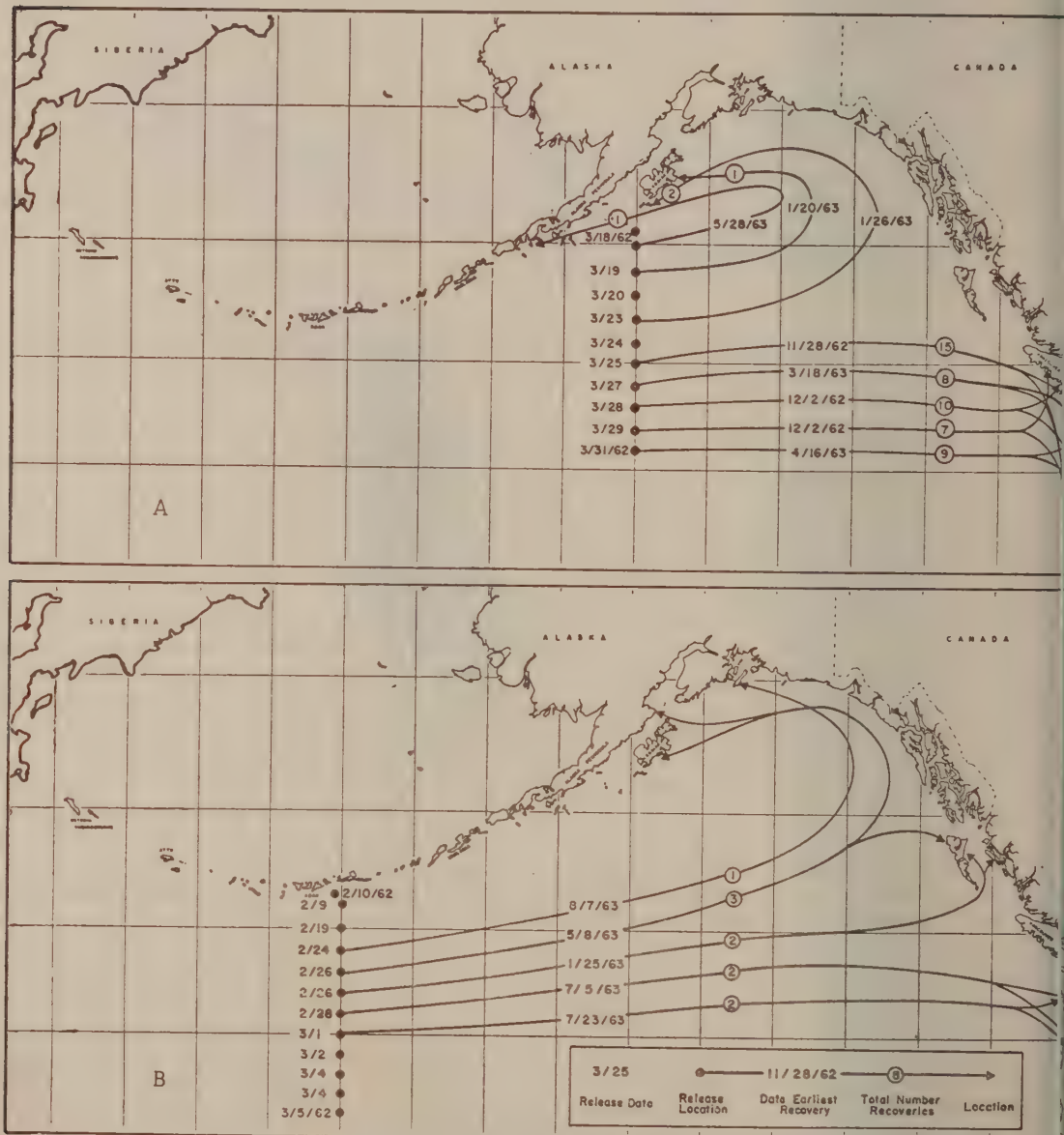


FIGURE 29. Release and recovery points of drift bottles (MV *Bertha Ann*, February–March 1962) as of August 1963

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**PARTIAL PURIFICATION OF A SUBSTANCE FROM STARFISH
TUBE FEET WHICH ELICITS ESCAPE RESPONSES
IN GASTROPOD MOLLUSCS**

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U. S. Bureau of Commercial Fisheries Biological Laboratory
La Jolla, California**

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PARTIAL PURIFICATION OF A SUBSTANCE FROM STARFISH TUBE FEET
WHICH ELICITS ESCAPE RESPONSES IN GASTROPOD MOLLUSCS

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Many species of gastropod molluscs along the California coast demonstrate escape responses when in the presence of, or contacted by, certain predatory starfish. The effectiveness of these responses in reducing predation by the ochre starfish, Pisaster ochraceus, and the sunflower starfish, Pycnopodia helianthoides, was considered by Feder (1963). Earlier work on gastropod responses to starfish was reported by Bullock (1953). Feder (1956) described preliminary efforts to characterize a substance responsible for gastropod escape reactions. However, the exact source and nature of this substance or substances remains to be resolved. This paper reports a series of observations and experiments on the isolation and characterization of the active substance in Pisaster ochraceus.

Methods and Results

Bioassay

The file limpet, Acmaea limatula, was used to bioassay starfish tissues by its escape response which we have quantified in the following way. When an intact tube foot or piece of dried tissue (< 0.2 mg) was touched to a limpet's mantle while the animal was under water, the following graded responses occurred according to the intensity of the stimulus. A "strong" response was recorded when all limpets tested in a trial raised their shells ("mushroomed") immediately (Feder, 1963, Bullock, 1953), extended their mantles over the edge of their shells, and moved directly away from the point of contact. Water-soluble extracts having this activity evoked the same response by diffusion under water without physical contact and at distances of 5 cm or less. "Moderate" responses were those in which all limpets tested displayed agitation by movement but no "mushrooming" or mantle extension. "Weak" responses were agitated movements in only an occasional, sensitive limpet. When file limpets failed to respond they were tested with fresh tube feet to be certain that they were normal and would elicit a "strong" response.

Escape reactions caused by tube feet epidermis

"Strong" reactions always follow contact of the limpet's mantle by the external epithelium of the oral and aboral surfaces and the parts of the water vascular system of Pisaster, e.g. the radial canals, tentacular ampullae and the tube feet. The tube feet were used as raw material to isolate the active substance because they are the most accessible of these structures. Excised tube feet maintain their ability to evoke strong responses for at least one year after storage at -15°C or if lyophilized and stored dry at room temperature.

Minute pieces of epidermis scraped from fresh or lyophilized tube feet elicit "strong" responses when touched to the mantle of a limpet, whereas tube feet with epidermis removed are inactive. Therefore the active agent is concentrated in the tube feet epidermis.

Extraction of an active fraction from tube feet epidermis

A partially purified and active extract can be made in the following way. Frozen starfish are thawed, placed oral side up and the surface of the tube feet scraped with a spatula to remove the epidermis. The epidermis is extracted with acetone for 24 hours at room temperature. The acetone is discarded and the residue is rinsed five times with 10 ml distilled water to remove the remaining acetone. The moist residue is ground rapidly in a mortar and washed into a centrifuge tube with a minimum of water. After centrifuging at 2400 X G for 30 minutes the supernatant is discarded and the centrifugate is lyophilized, ground to a fine powder and shaken vigorously for 15 minutes with an equal volume of dimethylsulfoxide (DMSO). The supernatant is recovered after 30 minutes centrifugation and the residue extracted again with DMSO until the residue has lost all activity on limpets. The combined supernatants are free of DMSO after lyophilization or drying under a stream of nitrogen and yield 5 to 10 mg of dry, concentrated starfish substance from an original 6 to 8 g of wet epidermis. The dry, active extract, when redissolved in water is colloidal and a small amount of insoluble material appears which can be removed by centrifugation.

Following each step in this extraction procedure, fractions were tested for their ability to elicit the escape response in file limpets. All active fractions were yellow in color. The results of these tests are summarized in table 1.

The final dry, pale yellow extract is soluble in DMSO, colloidal in water, insoluble in ethyl ether, acetone and petroleum ether. It is extremely stable when dry and can be kept indefinitely at room temperature. Light, heat (to 60°C) and air do not

TABLE 1
General appearance and test results of starfish extracts on the limpet *Acmaea limatula*.
Water temperature for limpets was maintained between 10 and 14°C. Test animals
were replaced at least once each week and sometimes more often. Tests were carried
out in separate containers of one liter capacity. The sea water from these was dis-
carded after each use.

Procedural Step	Derivatives	Appearance of derivatives	Preparation for testing	Appearance of dry material	Ability to evoke escape response
Epidermis removed from tube feet	Fresh epidermal material	brownish-orange	tested immediately	-----	strong
	Tube feet cores	white	tested immediately	-----	none to weak*
	Frozen and thawed epidermal material	brownish-orange	tested immediately	-----	strong
Acetone extraction	Acetone phase	deep orange	lyophilized	bright orange	none
	Residual epidermis	pale yellow	rinsed with distilled water	pale yellow hygroscopic	strong
Water extraction	Supernatant	pale yellow	lyophilized	pale yellow, hygroscopic	none to weak*
	Centrifugate	white	lyophilized	pale brown	strong
Dimethyl-sulfoxide extraction	Supernatant	yellow	lyophilized	brown-orange, hygroscopic	strong
	Centrifugate	dark orange	lyophilized	pale brown	none
Water extraction	Supernatant	yellow colloidal	lyophilized	pale yellow, hygroscopic	strong
	Centrifugate	pale yellow	lyophilized	pale yellow	moderate*

* - Not all active material is completely removed in this step.
This slight activity results from a small amount of active principle still retained in the centrifugate.

affect it. In water or slightly acid solution this material exhibited absorption peaks at 260 and 322 mμ.

The contaminant associated with the latter peak could be removed from the active substance by passage of the aqueous solution through Sephadex G-25 (50-100) mesh in a 1.5 X 18 cm column. With water elution a colloidal fraction came through the column in the first few ml after the bed volume, and when tested on limpets evoked strong escape responses. The succeeding aqueous fractions had no activity. When dried, the colloidal material was yellow. Ultrafiltration of the colloidal extract through a dialyzing membrane (Smith, 1958) resulted in a clear non-colloidal dialysate; when lyophilized, this was a yellow, viscous substance which elicited weak to strong reactions in limpets. The residue in the dialysis bag remained as active on limpets as the original extract, implying that the active substance is mostly adsorbed on the colloid.

We have found that other substances can induce the escape response in gastropods. For example strong salt solutions, distilled water alone, or water drawn from the oral region of a starfish (which may contain digestive enzymes) when applied to the mantle of Acmaea will elicit an escape response. Therefore, in all our tests we included controls to insure that it was the starfish substance causing the reaction. Extracts of tube feet epidermis from the sea star, Patiria miniata, a species which does not elicit responses in gastropod molluscs, constituted the major control throughout these experiments. Tests were also conducted on the two organic solvents used in the extraction procedures. Tube feet cores or inactive epidermal residues soaked in acetone or DMSO for 24 hours were completely inactive.

The active substance is probably linked to proteins in the tube foot and is released into the sea water where sensitive molluscs respond to its presence. The fact that it has been partially purified, is stable and can be separated from the colloidal material to which it is attached, opens the possibility of complete chemical analysis of this substance.

This work was supported in part by research grants from the National Science Foundation and the American Academy of Arts and Sciences. The assistance of Mr. Robert Smith and Mr. Andrew Cameron is gratefully acknowledged.

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There were only three returns in 1963 from chum salmon released in earlier years (one in 1961; two in 1962). All were recovered at sea and showed no new migration patterns.

Additional chum returns are expected from late run areas of Japan and from all areas of the U.S.S.R.

The distribution of pink salmon returns from releases west of 155°W. is shown in Figure 6. Returns from Gulf of Alaska releases are presented in tabular form (Table 2) because of their complex distribution.

The high seas returns from releases in area 8050 (Fig. 6) indicate that most pink salmon were bound for Asia as in previous odd-numbered years. There will probably be returns received from East Kamchatka. The one Norton Sound return shows the presence of some North American pink salmon in the central Aleutian area in an odd-numbered year. Returns from releases south of the Shumagin Islands near 50°N., 160°W. extend the known eastward limit of Asian pink salmon from 163°W. to about 158°W. The three returns from tagging by the Alaska Department of Fish and Game are the first evidence that Asian pink salmon migrate through American coastal fishery areas. The three fish were tagged on June 15 and 23 in East Anchor Cove on the south side of Unimak Island (approximately 54°40'N., 163°10'W.).¹ A number of other returns from Alaska Department of Fish and Game experiments were from Western Alaska.

The results of U.S. operations in the Gulf of Alaska (Table 2) show only a partial picture of pink salmon distribution because fishing areas assigned to the two Gulf vessels covered only the western and northern Gulf as described earlier. A more complete picture will be obtained when Canadian results are considered together with U.S. results. As in 1962, there was a general mixing of Alaska Peninsula, Kodiak Island, Prince William Sound, and Icy Strait stocks throughout many of the areas fished by U.S. vessels. Returns from the remainder of Southeastern Alaska and from B.C. were from releases only in the north central and northeastern Gulf. No U.S. tags were received from the large 1963 run of pink salmon to the Fraser River and Puget Sound, suggesting that these stocks were not numerous in the western or northern Gulf.

The distribution of coho returns in 1963 is illustrated in Figure 7. The specimen tagged south of Kodiak and recovered in the Kuskokwim River extends the

known distribution for Kuskokwim coho salmon. The specimen recovered a year after tagging is also of interest. At tagging on July 23, 1962, it was only 29.5 cm. long, indicating that it had migrated a considerable distance northward (700–800 miles), while relatively small, and in a short time, since it had presumably entered salt water in April or May. An additional two coho (not illustrated) tagged near Cape Flattery, Washington, were recovered in the Strait of Juan de Fuca and Puget Sound, respectively.

LABORATORY WORK

Now that previous years' data have been entered on IBM cards, several new analyses of the data are being undertaken.

In addition, new studies of scales from tagged mature and immature sockeye salmon are being undertaken to supplement the tag return data from several key areas of intensive tagging.

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SALMON DISTRIBUTION AND ABUNDANCE ON THE HIGH SEAS— SUMMER SEASON—1963

by R. French

Research on salmon distribution and abundance in 1963 covered two general regions in winter and summer seasons, the central Aleutian Islands area and the western Gulf of Alaska. In the winter the chartered vessel *MV Bertha Ann* fished in the Bering Sea along longitudes 180° and 175°E., and along 180° in the North Pacific Ocean; in the summer the vessel fished in the Gulf of Alaska along longitude 162°W. The Bureau of Commercial Fisheries research vessel *MV George B. Kelez* was employed along longitude 165°W. during the winter cruise and in the North Pacific south of Adak Island in the summer.

Results of the winter cruises in 1962 and 1963 are reported under a separate heading. This section presents preliminary results of the summer cruises.

Objectives of the summer research were: (1) to determine distribution of salmon stocks by repetitive fishing from early July to the middle of September south of Adak Island and the Alaska Peninsula, (2)

¹ Release data from Alaska Department of Fish and Game; recovery data from Fisheries Agency of Japan.

TABLE 5. Salmon catches by United States

MV *George B. Kelez*

Set no.	Date	Position		Surf. temp. °C.	No. of shack- les	Sockeye						Total
		Lat. N.	Longitude			Mesh size						
						5½	4½	3½	2½	M4½	M3½	
1	7/3	51°23'	176°20'W.	7.3	32	2	4	5	0	2	1	14
2	7/4	51°10'	176°15'W.	7.7	32	7	18	5	0	2	2	34
3	7/5	51°31'	176°20'W.	7.9	32	0	0	0	0	0	0	0
4	7/7	51°17'	176°25'W.	8.1	32	0	10	6	2	5	15	38
5	7/8	50°49'	176°19'W.	8.8	32	3	26	8	2	9	2	50
6	7/9	51°25'	176°23'W.	9.0	32	2	24	11	1	7	4	49
7	7/10	51°32'	176°19'W.	7.4	32	1	3	5	1	0	0	10
8	7/11	51°20'	176°15'W.	8.9	32	2	20	14	2	4	1	43
9	7/15	50°54'	176°19'W.	8.8	32	0	1	6	0	1	1	9
10	7/17	51°14'	176°17'W.	8.2	32	6	69	45	8	17	16	161
11	7/18	51°22'	176°24'W.	8.0	32	17	163	80	19	41	36	356
12	7/19	50°30'	176°20'W.	9.4	32	0	8	21	2	3	8	42
13	7/20	50°55'	176°22'W.	9.9	32	4	64	94	10	9	41	222
14	7/23	51°14'	176°20'W.	9.1	32	7	42	109	6	20	65	249
15	7/26	51°29'	176°22'W.	7.9	32	13	213	426	68	37	235	992
16	7/29	51°35'	176°22'W.	9.5	12	4	24	33	11	—	—	72
17	7/30	51°17'	176°19'W.	9.7	32	7	94	48	7	9	27	192
18	7/31	50°54'	176°19'W.	10.4	32	4	89	41	5	16	34	189
19	8/2	50°00'	176°26'W.	11.1	32	1	17	4	0	2	0	24
20	8/3	50°28'	176°20'W.	10.6	32	1	95	89	8	20	37	250
21	8/4	51°04'	176°20'W.	10.6	32	5	81	85	19	40	100	330
22	8/5	51°35'	176°22'W.	6.9	18	—	27	190	74	—	—	294
23	8/11	51°28'	176°19'W.	7.3	18	9	31	208	85	—	—	333
24	8/12	51°09'	176°19'W.	8.8	32	6	48	39	4	6	12	115
25	8/13	50°34'	176°19'W.	11.3	32	1	48	35	3	6	11	104
26	8/14	50°00'	176°19'W.	12.2	32	0	11	11	1	5	2	30
27	8/15	50°47'	176°18'W.	11.9	32	1	8	6	1	2	2	20
28	8/18	50°25'	176°24'W.	9.4	18	4	11	67	17	—	—	99
29	8/19	51°32'	176°29'W.	7.9	18	1	9	77	27	—	—	114
30	8/20	51°36'	176°01'W.	7.1	18	0	6	81	12	—	—	99
31	8/22	51°26'	176°23'W.	10.1	18	2	12	60	35	—	—	109
32	8/23	51°28'	176°23'W.	9.9	18	6	14	22	4	—	—	46
33	8/26	51°20'	176°19'W.	11.1	18	2	8	11	14	—	—	35
34	8/27	51°19'	176°17'W.	10.5	32	2	11	22	4	0	8	47
35	8/28	51°25'	176°18'W.	10.2	32	5	31	41	7	6	10	100
36	8/29	51°26'	176°24'W.	10.0	32	4	15	26	8	2	18	73
37	8/30	51°22'	176°22'W.	9.9	32	0	4	19	6	0	10	39
38	8/31	51°16'	176°22'W.	9.5	32	6	31	23	1	1	11	73
39	9/1	50°52'	176°22'W.	11.1	32	1	7	6	2	1	6	23
40	9/2	50°01'	176°19'W.	11.1	32	0	16	19	2	1	9	47
41	9/4	50°38'	176°26'W.	10.8	32	1	77	16	2	6	16	118
42	9/9	51°24'	176°23'W.	10.6	24	3	37	46	10	—	—	96
43	9/11	50°35'	176°19'W.	11.2	24	1	21	19	6	—	—	47
Totals						144	1,548	2,179	496	280	740	5,387

Note: M4½ and M3½ refer to monofilament nets; — indicates they were not fished in these sets.

research vessels, summer season, 1963.

Chum							Pink											Coho	Chi-nook	Total salmon catch	Steel-head
Mesh size							Mesh size														
5½	4½	3½	2½	M4½	M3½	Total	5½	4½	3½	2½	M4½	M3½	Total								
0	1	2	7	2	1	13	0	5	1	0	4	0	10	0	0	37	0				
1	8	4	10	2	5	30	1	4	0	0	1	0	6	2	0	72	0				
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
1	1	10	14	0	0	26	0	2	0	0	0	0	2	0	0	66	0				
0	4	5	8	3	2	22	1	9	0	0	3	0	13	7	0	92	1				
4	15	19	31	4	10	83	4	86	0	0	21	1	112	13	0	257	0				
1	8	5	40	1	0	55	2	7	0	0	1	0	10	2	1	78	0				
0	2	0	0	1	0	3	2	6	1	0	3	0	12	5	0	63	0				
0	8	5	1	3	1	18	0	1	0	0	1	0	2	17	0	46	0				
2	19	7	1	2	2	33	2	7	0	0	2	0	11	54	0	259	2				
3	22	5	14	4	1	49	0	5	0	0	0	0	5	103	0	513	0				
1	16	1	0	3	0	21	0	0	0	0	0	0	0	292	0	355	0				
0	16	9	0	2	1	28	0	1	0	0	0	0	1	280	1	532	2				
0	2	3	1	3	0	9	1	1	1	0	0	0	3	11	1	273	0				
1	27	6	0	3	2	39	0	4	0	0	2	0	6	10	0	1,047	0				
2	15	1	3	—	—	21	0	3	0	0	—	—	3	5	0	101	0				
3	33	2	0	2	3	43	1	6	0	0	0	1	8	65	12	210	10				
3	40	5	0	5	1	54	0	2	0	0	0	0	2	29	1	210	11				
2	84	5	0	5	3	99	0	0	0	0	0	0	0	30	4	100	0				
3	20	4	0	5	3	35	0	0	0	0	0	0	0	13	0	200	5				
9	67	2	0	4	3	85	0	0	0	0	0	0	0	95	4	511	5				
2	13	59	2	—	—	76	1	0	0	0	—	—	1	11	1	363	0				
2	32	40	1	—	—	75	0	0	0	0	—	—	0	10	2	420	0				
0	23	4	0	3	6	36	0	0	0	0	0	0	0	9	1	161	2				
6	40	10	0	3	3	62	0	0	0	0	0	0	0	0	0	166	3				
3	52	3	0	8	4	70	0	0	0	0	0	0	0	0	0	100	2				
0	3	0	0	0	0	3	0	0	0	0	0	0	0	5	0	28	0				
4	59	70	2	—	—	135	0	1	0	0	—	—	1	5	0	240	0				
13	151	106	3	—	—	273	1	1	0	0	—	—	2	2	0	391	0				
2	22	27	1	—	—	52	0	0	0	0	—	—	0	0	0	151	0				
3	42	11	4	—	—	60	0	2	0	0	—	—	2	3	0	174	0				
0	48	12	5	—	—	75	0	0	0	0	—	—	0	13	0	124	0				
4	19	2	1	—	—	22	0	0	0	0	—	—	0	1	0	62	2				
1	38	10	0	4	—	57	0	0	0	0	0	0	0	1	3	108	3				
1	72	22	1	7	4	107	0	2	0	0	0	0	2	3	0	212	1				
2	64	81	2	3	17	169	1	0	1	0	0	0	2	5	2	251	2				
2	54	17	1	8	8	88	0	0	0	0	0	0	0	1	1	120	6				
5	42	9	0	7	1	64	0	0	0	0	0	0	0	2	0	139	7				
0	7	0	0	1	0	8	0	0	0	0	0	0	0	1	0	32	4				
1	17	1	0	2	2	23	0	0	0	0	0	0	0	0	0	70	3				
1	6	0	0	3	0	10	0	0	0	0	0	0	0	0	0	128	9				
10	60	7	1	—	—	78	0	3	0	0	—	—	3	1	1	179	10				
1	15	1	0	—	—	17	0	0	0	0	—	—	0	0	0	64	5				
99	1,287	592	154	103	85	2,320	17	158	4	0	38	2	219	1,106	36	9,068	95				

Set no.	Date	Position		Surf. temp. °C.	No. of shackles	Mesh size				Mesh size				Total	Coho	Chi-nook	Steel-salmon catch							
		Lat. N.	Longitude			5½	4½	3½	2½	5½	4½	3½	2½											
1	7/22	54°01'	162°03'W.	9.4	32	2	8	3	6	19	0	4	1	0	5	10	29	0	0	39	0	0	63	0
2	7/23	53°00'	162°00'W.	9.5	32	2	21	86	60	169	0	17	13	1	31	0	3	1	0	4	1	0	205	3
3	7/24	51°59'	162°04'W.	9.5	32	3	30	28	17	78	5	45	10	4	64	0	3	0	0	3	1	0	146	4
4	7/25	51°00'	162°00'W.	9.8	32	7	71	52	5	135	3	30	10	2	45	0	4	0	0	4	3	0	187	7
5	7/26	50°00'	162°00'W.	10.6	32	0	14	6	0	20	0	5	4	0	9	0	0	0	0	0	1	0	30	0
6	7/27	49°00'	162°00'W.	11.3	32	2	2	2	0	6	2	13	1	0	16	0	0	0	0	0	2	0	24	0
7	7/28	50°30'	162°00'W.	10.5	32	0	35	9	1	45	3	31	16	1	51	0	0	0	0	0	1	1	98	0
8	7/29	51°31'	162°02'W.	10.6	32	6	107	138	35	286	2	76	24	1	103	0	1	0	0	1	3	1	394	4
9	7/30	52°30'	162°00'W.	10.8	32	3	6	15	5	29	2	26	19	2	49	2	8	0	0	10	2	0	90	11
10	7/31	53°30'	162°00'W.	10.5	32	2	11	18	11	42	5	26	6	0	37	1	2	0	0	3	1	0	83	7
11	8/1	54°30'	162°00'W.	10.2	32	0	0	0	0	0	0	1	1	0	2	0	0	0	0	0	1	0	3	0
12	8/2	54°30'	159°57'W.	10.2	32	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	0	0	2	0
13	8/3	53°30'	160°00'W.	11.0	32	1	5	6	2	14	2	28	6	0	36	0	4	0	0	4	1	0	55	12
14	8/4	52°30'	160°00'W.	11.4	32	0	1	3	2	6	2	29	31	2	64	0	0	0	0	0	1	0	71	1
15	8/5	51°30'	162°00'W.	11.4	32	2	49	90	18	159	2	32	14	1	49	0	2	0	0	2	2	0	212	9
16	8/6	52°00'	162°00'W.	10.9	32	4	55	93	29	181	3	62	24	5	94	0	1	1	0	2	1	0	278	5
17	8/7	52°20'	162°00'W.	11.3	32	4	24	59	10	97	3	99	30	5	137	0	0	0	0	0	3	0	237	11
18	8/8	52°40'	162°00'W.	11.3	32	2	10	29	8	49	0	20	20	1	41	0	4	0	0	4	5	0	99	3
19	8/9	55°00'	162°00'W.	11.3	32	2	4	27	5	38	2	52	28	2	84	1	2	0	0	3	0	0	125	3
20	8/10	53°20'	162°00'W.	11.3	29	3	12	33	5	53	2	70	34	1	107	0	1	0	0	1	2	0	163	1
21	8/11	53°40'	162°00'W.	11.3	32	2	1	10	1	14	1	40	14	0	55	0	0	0	0	0	0	0	69	3
22	8/12	54°00'	162°00'W.	10.7	32	11	48	18	7	84	19	110	99	16	244	1	7	2	0	10	6	1	345	1
23	8/15	54°19'	162°00'W.	10.5	32	0	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	2	0
24	8/16	53°40'	162°00'W.	11.5	32	2	5	12	5	24	1	39	23	1	64	0	0	0	0	0	0	0	88	2
25	8/17	53°00'	161°59'W.	11.6	32	2	7	12	2	23	1	33	14	1	49	0	0	0	0	0	0	0	72	1
26	8/18	52°20'	162°00'W.	11.6	32	0	12	23	5	40	2	40	16	2	60	0	0	0	0	0	0	0	100	5
27	8/19	51°40'	162°00'W.	11.4	32	2	27	33	4	66	0	25	8	0	33	0	0	0	0	0	1	0	100	3
28	8/20	51°00'	162°00'W.	11.6	32	6	105	84	8	203	4	33	14	1	52	0	0	0	0	0	0	0	255	3
29	8/21	50°20'	162°00'W.	11.9	32	4	35	32	3	74	2	12	9	0	23	0	0	0	0	0	1	0	98	0
30	8/22	49°40'	162°00'W.	12.9	32	1	40	12	1	54	0	0	0	0	0	0	0	0	0	0	0	0	54	1
31	8/24	49°00'	162°00'W.	12.9	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	8/25	50°40'	162°00'W.	11.6	32	5	71	63	4	143	4	64	24	0	92	0	0	0	0	0	0	0	235	2
33	8/26	51°20'	162°00'W.	11.5	32	6	68	54	4	132	2	45	14	0	61	0	0	0	0	0	0	0	193	5

[illegible]

to compare efficiency of monofilament and multifilament gillnets, (3) to compare catches by purse seine and gillnet, (4) to determine the potential of a giant pelagic trawl for catching salmon.

Fishing was conducted with gillnets as in past seasons. Both vessels used the standard INPFC basic net string of 24 nets, each 50 fathoms long, with mesh sizes $2\frac{3}{4}$ ", $3\frac{1}{4}$ ", $4\frac{1}{2}$ " and $5\frac{1}{4}$ " (stretched measure). Additional $3\frac{1}{4}$ " and $4\frac{1}{2}$ " mesh nets were added on the end of the string to increase sample sizes. The MV *George B. Kelez* also employed four monofilament gillnets, two each of $3\frac{1}{4}$ " and $4\frac{1}{2}$ " mesh.

CATCH DATA

Catches made during the summer cruises are listed in Table 5. Main features of the summer catches were the abundance of one-winter-at-sea sockeye salmon and of coho salmon in the Aleutian area. The total of 1,166 coho salmon represents the most we have ever taken during high seas research cruises.

DISTRIBUTION AND RELATIVE ABUNDANCE

The distribution and relative abundance of sockeye from repetitive fishing south of Adak Island to latitude 50°N. is given in Table 6. Results of tabulating average catch per shackle by time periods and distance offshore show the greatest relative abundance of one-winter-at-sea sockeye salmon to occur near the end of July and within 15 miles of shore. Border averages here and in Tables 7, 8 and 9 were computed for times and areas fished; I recognize that different results might be obtained if all times and areas had been sampled. The largest single catch per shackle of one-winter sockeye (46.2 fish) came from the set of July 26 made 15 miles offshore. The older sockeye also showed greatest abundance during the period July 21-31 but were approximately equally abundant in the inshore area and between 31 and 45 miles offshore.

Chum salmon catches indicated the greatest average abundance of two-year fish to be within 50 miles of shore, in early and mid-August (Table 7). Older chum salmon appeared most abundantly during late August, although only stations within 30 miles of shore were fished in this period.

Results of repetitive fishing south of the Alaska Peninsula along longitude 162°W. are given in Tables 8 and 9. North-south gradations are listed in latitudes because of the large distance, approximately 360 miles, covered during the cruise. The greatest average abundance of both one-winter-at-sea and the older

TABLE 6. Average catch per shackle, one-winter-at-sea and older sockeye salmon, by time periods and distances south from Adak Island, 1963.

Time period	Miles from Adak Island					Average
	0-15	16-30	31-45	46-60	61-100	
<i>One-winter-at-sea sockeye</i>						
7/ 1-10	0.4	0.2	0	0.2	—	0.20
7/11-20	—	3.3	2.7	4.5	1.9	3.10
7/21-31	46.2	7.3	—	3.4	—	18.97
8/ 1-10	10.2	—	8.7	—	3.8	7.57
8/11-20	15.7	26.3	3.5	0.7	2.1	9.66
8/21-31	15.7	2.9	—	—	—	9.30
9/ 1-11	—	7.0	—	0.6	1.9	3.17
Average	17.64	7.83	4.97	1.88	2.43	
<i>Two- and three-winter-at-sea sockeye</i>						
7/ 1-10	0.1	0.3	0.7	1.1	—	0.55
7/11-20	—	5.0	3.0	1.8	0.3	2.53
7/21-31	11.0	2.9	—	4.7	—	6.20
8/ 1-10	1.2	—	4.2	—	3.1	2.83
8/11-20	0.2	0.8	2.2	0.4	1.6	1.04
8/21-31	0.7	0.4	—	—	—	0.55
9/ 1-11	—	1.9	—	0.4	2.0	1.43
Average	2.64	1.88	2.53	1.68	1.75	

"0" indicates no fish.

"—" indicates no sampling.

TABLE 7. Average catch per shackle, two-year and older chum salmon, by time periods and distances south from Adak Island, 1963.

Time period	Miles from Adak Island					Average
	0-15	16-30	31-45	46-60	61-100	
<i>Two-year chum</i>						
7/ 1-10	4.3	2.0	1.2	1.3	—	2.20
7/11-20	—	0.9	0.6	0.7	0.1	0.58
7/21-31	0.5	0.2	—	0.4	—	0.37
8/ 1-10	9.5	—	0.2	—	0.1	3.27
8/11-20	4.5	11.3	0.2	0	0.5	3.30
8/21-31	2.0	2.0	—	—	—	2.10
9/ 1-11	—	0.6	—	0	0.1	0.23
Average	4.16	2.83	0.55	0.48	0.20	
<i>Three-year and older chum</i>						
7/ 1-10	0.2	0.2	0.4	0.2	—	0.25
7/11-20	—	0.6	0.9	0.7	0.7	0.73
7/21-31	1.7	1.4	—	2.3	—	1.80
8/ 1-10	1.2	—	4.1	—	3.0	2.77
8/11-20	1.8	7.1	1.2	0.2	2.8	2.62
8/21-31	3.8	3.0	—	—	—	3.40
9/ 1-11	—	3.3	—	0.4	0.7	1.47
Average	1.74	2.60	1.65	0.76	1.80	

"0" indicates no fish.

"—" indicates no sampling.

TABLE 8. Average catch per shackle of one-winter-at-sea and older sockeye salmon, by time periods and latitudes along longitude 162°W., 1963.

Time period	Latitude north					Average
	N. of 53°30'	52°30'–53°30'	51°30'–52°30'	50°30'–51°30'	S. of 50°30'	
<i>One-winter-at-sea sockeye</i>						
7/21–31	0.7	5.1	8.2	1.8	0.1	3.18
8/ 1–10	0	2.3	4.9	8.4	—	3.90
8/11–20	1.0	1.2	2.4	6.5	—	2.78
8/21–31	1.3	0.7	1.9	4.7	0.9	1.90
9/ 1–10	—	0.5	3.3	3.4	1.7	3.48
9/11–13	0.1	—	—	—	—	0.10
Average	0.62	1.96	4.14	5.96	0.90	
<i>Two- and three-winter-at-sea sockeye</i>						
7/21–31	0	0.3	2.5	2.9	0.5	1.24
8/ 1–10	0	0.2	1.2	2.2	—	0.90
8/11–20	0	0.2	1.0	5.3	—	1.62
8/21–31	0	0.2	0.6	3.7	1.3	1.16
9/ 1–10	—	0.1	1.4	2.5	0.1	1.03
9/11–13	0.1	—	—	—	—	0.10
Average	0.02	0.20	1.34	3.32	0.63	

"0" indicates no fish.

"—" indicates no sampling.

TABLE 9. Average catch per shackle of two-year and older chum salmon, by time periods and latitudes along longitude 162°W., 1963.

Time period	Latitude north					Average
	N. of 53°30'	52°30'–53°30'	51°30'–52°30'	50°30'–51°30'	S. of 50°30'	
<i>Two-year chum</i>						
7/21–31	0.1	0.8	1.0	0.9	0.2	0.60
8/ 1–10	0.1	0.7	2.0	0.8	—	0.90
8/11–20	2.5	1.0	1.0	0.7	—	1.30
8/21–31	0.5	0.9	0.6	1.1	0.2	0.66
9/ 1–10	—	0.2	0	0.6	1.2	0.50
9/11–13	1.2	—	—	—	—	1.20
Average	0.88	0.72	0.92	0.82	0.53	
<i>Three-year and older chum</i>						
7/21–31	0.1	0.9	2.9	1.4	0.4	1.14
8/ 1–10	0	2.1	2.9	1.3	—	1.58
8/11–20	2.4	1.7	1.7	1.9	—	1.93
8/21–31	1.9	0.7	1.0	2.9	0.2	1.34
9/ 1–10	—	0.4	0.1	1.4	0.9	0.70
9/11–13	0.4	—	—	—	—	0.40
Average	0.96	1.16	1.72	1.78	0.50	

"0" indicates no fish.

"—" indicates no sampling.

keye salmon occurred between latitudes 50°30'N. and 51°30'N. While the juvenile sockeye abundance was indicated to peak during the periods August 1-10 and September 1-10, older sockeye were most abundant during August 11-20.

Chum salmon were distributed somewhat differently from the sockeye in time and area along longitude 162°W. (Table 9). The young chum salmon were most abundant in mid-August and were approximately equally abundant from latitude 50°30'N. to the north-

ern limits of sampling. The catch of older chum also reached the maximum during mid-August but was greatest between latitudes 50°30'N. and 52°30'N.

Among the other salmon species commonly taken during the summer season, coho salmon were most abundant during 1963. Most of the pink salmon had departed for the spawning streams prior to the start of fishing. Of the 1,106 coho salmon taken by the MV *George B. Kelez* south of Adak, most came from three sets on July 18, 19 and 20 at distances of from 22 to 74 miles of shore (between latitudes 50°30'N. and 51°22'N.).

COMPARISON OF PURSE SEINE AND GILLNET CATCHES

Table 10 gives the results of comparative fishing between the MV *George B. Kelez* using gillnets and the Fisheries Research Institute charter vessel *Commander* using a purse seine. Total catches of the two vessels, of course, depend entirely upon the number of gillnets fished and number of purse seine hauls made. The results listed are illustrative of catches made by the two vessels during normal fishing operations. Following the usual practice gillnets were fished at night and purse seines during the day.

Comparisons of sockeye catches per unit of gear (Figures 8 and 9) indicate both kinds of gear reflect the trend of abundance in a similar manner; however, there is a difference between types of gear in relative efficiency of catch of the two age groups. The seine took relatively more one-winter sockeye than gillnets. Analyses of other features of the joint fishing are continuing.

COMPARISON OF MONOFILAMENT AND MULTIFILAMENT GILLNET CATCHES

During the first phase of the mono-multifilament gillnet experiment (French, 1963; Larkins, 1963), four shackles of monofilament nets were *alternated* with multifilament nets of like mesh size; results indicated that the efficiency of the monofilament nets was between two and six times that of the multifilament nets (Table 11, section a). This year, four *adjoining* shackles of monofilament nets (same mesh sizes as in 1962) were fished with a control section of multifilament nets at the end of the standard 24-net string. The monofilament nets were separated from the other nets by a 5-fathom hole.

For both mesh sizes the monofilament slightly out-

TABLE 10. Total gillnet and purse seine catches made during comparative fishing of *George B. Kelez* and *Commander* south of Adak Island, 1963.

Date	Approx. distance offshore	Vessel and fishing effort	Total catch					Total
			Sockeye	Chum	Pink	Coho	Chinook	
July 8	22	<i>Commander</i> —3 hauls (seine)	26	189	6	0	0	221
		<i>Kelez</i> —32 shackles (gillnet)	49	83	112	13	0	257
July 9	11	<i>Commander</i> —3 hauls	3	6	11	0	2	22
		<i>Kelez</i> —32 shackles	10	55	10	2	1	78
July 10	19	<i>Commander</i> —3 hauls	124	83	7	5	1	220
		<i>Kelez</i> —32 shackles	43	3	12	5	0	63
July 17	34	<i>Commander</i> —3 hauls	165	17	7	19	0	208
		<i>Kelez</i> —32 shackles	161	33	11	54	0	259
July 19	22	<i>Commander</i> —1 haul	54	18	3	0	1	76
		<i>Kelez</i> —32 shackles	356	49	5	103	0	513
July 27	15	<i>Commander</i> —3 hauls	334	54	0	2	1	391
		<i>Kelez</i> —32 shackles	992	39	6	10	0	1,047
July 28	18	<i>Commander</i> —3 hauls	145	25	1	6	2	179
		<i>Kelez</i> —12 shackles	72	21	3	5	0	101
Aug. 4	14	<i>Commander</i> —1 haul	245	85	0	0	0	330
		<i>Kelez</i> —18 shackles	294	76	1	11	1	383
Totals		<i>Commander</i> —20 hauls	1,096	477	35	32	7	1,647
		<i>Kelez</i> —242 shackles (8 sets)	1,977	359	160	203	2	2,701

Commander data from Fisheries Research Institute.

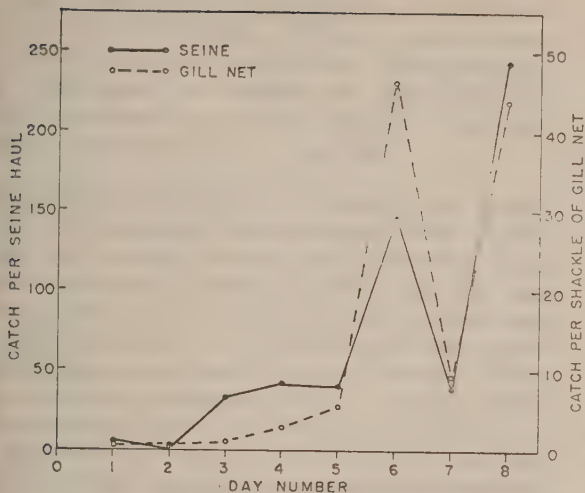


FIGURE 8. Comparison of catch per seine haul and catch per shackle of gillnet, one-winter-at-sea sockeye salmon, south of Adak Island, July 9-August 4, 1963.

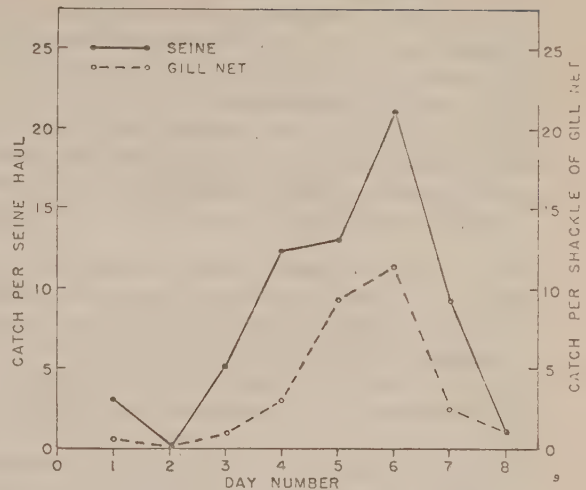


FIGURE 9. Comparison of catch per seine haul and catch per shackle of gillnet, two- and three-winter-at-sea immature sockeye salmon, south of Adak Island, July 9-August 4, 1963.

TABLE 11. Comparison of salmon catches in monofilament and multifilament gillnets, 1962 and 1963 seasons.

		4½" multi-				4½" mono-			3½" multi-			3½" mono-		
	Season	No. sets	No. fish	No. nets	c/ net	No. fish	No. nets	c/ net	No. fish	No. nets	c/ net	No. fish	No. nets	c/ nets
(a) ¹⁾														
Comparison of salmon catches in mono- and multifilament gillnets when the two are alternated (1962).	Spring	16	950	404	2.35	500	32	15.62	—	—	—	—	—	—
	Summer	28	3003	434	6.91	750	45	16.67	1650	215	7.67	1169	47	24.87
	Total	44	3953	838	4.71	1250	77	16.23	—	—	—	—	—	—
(b)														
Comparison of salmon catches in mono- and multifilament gillnets when all monofilament nets are adjoining (1963).	Summer	23	2401	322	7.46	533	46	11.59	1338	138	9.70	709	46	15.41
(c)														
Relative efficiency of monofilament gillnets when alternated with multifilament nets and when joined together.					4½"		3½"							
					2.33		3.22		Alternated (summer, 1962)					
					1.55		1.59		Adjoined (summer, 1963)					

¹⁾ Data from French (1963).

fished the multifilament nets over the entire season, although in 10 of the 22 sets compared, one or both of the monofilament mesh sizes was less efficient than the comparable multifilament nets (Table 11, section b). The relative efficiency of the monofilament nets for both mesh sizes (Table 11, section c) was considerably lower in 1963 than in 1962, indicating that the high catches in these nets are at least partially dependent on the proximity of multifilament nets.

The mono-multifilament net comparison will be

subjected to additional analysis when final catch records are available.

EXPERIMENTAL TRAWLING FOR SALMON

Experimental trawling for salmon was conducted by the Bureau's MV *John N. Cobb* in a joint fishing operation with the MV *George B. Kelez*. The trawl used was the Cobb Pelagic Trawl (McNeely, 1963), a giant trawl with a mouth opening of approximately 7,200 square feet, towed at 2.5 knots.

During the test fishing, an average of four 1-hour to 4-hour trawls were made each day. A total catch of 117 salmon (97 sockeye, 19 chum, one coho) was made in 38 tows, an average of about three salmon per tow. The trawl was selective for small fish; all sockeye were one-winter-at-sea fish and 79 per cent of the chum salmon were two-year fish.

Most salmon captured were gilled in the body meshes rather than collected in the cod end. This may indicate that the trawl retained only the size fish which would gill in the $3\frac{1}{4}$ " mesh, and that larger fish may have escaped. Most salmon were taken at night and during surface tows; direction of tow did not appear to make any appreciable difference in catches. Presence of salmon in the area during the trawl test period is illustrated by the catches of the *George B. Kelez* sets 28–38 (Table 5). During the first part of the joint fishing the *Kelez* averaged 191 salmon using 18 shackles, and averaged 168 salmon using 32 shackles during the end of the fishing period.

Additional analyses of the trawl catches will be made when final catch records are available.

INCIDENTAL ALBACORE CATCHES

Larkins (1964) observed that 37 species other than salmon have been taken in surface gillnets during the high seas salmon research program. One species, albacore, has been taken in the southernmost areas during salmon research cruises, but rarely in a set where salmon were captured. In 1963 the *Bertha Ann* captured seven albacore along with 54 sockeye at latitude $49^{\circ}40'N$. and longitude $162^{\circ}W$. on August 22. Surface water temperature was $12.9^{\circ}C$. The *Bertha Ann* also took albacore at latitude $49^{\circ}N$. and longitude $162^{\circ}W$. on August 24, and at latitude $49^{\circ}30'N$. and longitude $162^{\circ}W$. on September 7. No salmon were taken in these sets.

SUMMARY

Salmon research cruises during the summer season were concentrated south of Adak Island in the Aleutian Islands area and in the Gulf of Alaska along longitude $162^{\circ}W$. Research objectives were to determine the distributional features of salmon passing these areas, to continue studies on the comparison of the efficiency of monofilament and multifilament gillnets and to compare salmon catches of gillnets and purse seines fished jointly. In addition, field tests of a large pelagic trawl were conducted in the Aleutian area.

Fishing in the area between Adak Island and latitude $50^{\circ}N$., a distance of about 100 miles, produced the

largest catches of one-winter-at-sea sockeye during the period July 21–31 and within 15 miles of shore. Catches of older sockeye also were largest from July 21–31 and were about equal within 15 miles of shore and between 31 to 45 miles offshore. Average catch of juvenile chum salmon (two-year fish) was highest during the period August 11–20 and within 15 miles of shore; for older chum catches were largest during August 11–20 and between 16 to 30 miles of shore.

In the Gulf of Alaska along longitude $162^{\circ}W$., catches of one-winter-at-sea sockeye were largest during July 21–31 between latitudes $50^{\circ}30'N$. and $52^{\circ}30'N$. Older sockeye were equally abundant in the catch during the periods July 21–31 and August 21–31, and most abundant between latitudes $50^{\circ}30'N$. and $51^{\circ}30'N$. Two-year chum salmon were most numerous in the catches during August 11–20 and about equally distributed from latitudes $50^{\circ}30'N$. to $53^{\circ}30'N$. The older chum salmon catches also peaked during this period and were greatest between latitudes $50^{\circ}30'N$. and $52^{\circ}30'N$.

Results of test fishing by gillnets and purse seines in the same area at similar time periods indicate both kinds of gear reflect trends in abundance of sockeye salmon in a similar manner.

Tests of the relative efficiency of monofilament and multifilament gillnets indicate that the higher catches recorded last year in monofilament nets may, in part, be dependent upon the proximity of multifilament nets.

Small catches, about three salmon per tow, were made during experimental trawling for salmon in the Aleutian area using a giant pelagic trawl.

Sockeye salmon and albacore were taken in a gillnet set at latitude $49^{\circ}40'N$. and longitude $162^{\circ}W$. This was only the second time these two species were taken together in a salmon research cruise in the Aleutian area or Gulf of Alaska.

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SALMON DISTRIBUTION AND ABUNDANCE ON THE HIGH SEAS—WINTER SEASON 1962 AND 1963

by R. French and J. E. Mason

Biologists of Canada, Japan and the United States have gathered considerable information about the distribution, abundance and migrations of salmon in spring and summer. Little is known, however, for the winter season. Do salmon remain in the Bering Sea or migrate southward into the Pacific Ocean? Do they congregate in particular areas of the North Pacific Ocean? Do they intermingle by species, age groups, or maturity?

To explore this phase of salmon life history, and particularly to determine the feasibility of winter cruises at these northern latitudes, the chartered vessel *MV Bertha Ann* and the Bureau of Commercial Fisheries vessel *MV George B. Kelez* fished (Fig. 10) in the Bering Sea and the central and eastern North Pacific Ocean during January–April 1962 and January–March 1963. French (1963), French and Mosher (1962) and Hunter and Larkins (1962) have given preliminary accounts of work of these two winters. Favorite and Morse (1962) reported environmental features found in 1962. The present report details biological findings and evaluates the feasibility of winter fishing.

VESSELS AND GEAR

Schooners and seiners previously chartered for

spring and summer work were 65 to 80 feet long; this was considered too small for winter operations far offshore. The *Bertha Ann* and *George B. Kelez*, on the other hand, are converted U.S. Navy surplus vessels, 176 feet in length, capable of withstanding winter storms in the North Pacific. They not only are safer for such work than the smaller vessels, but each has a protected area in the hold for net repair and more adequate facilities for scientists and crew during extended cruises.

As in spring and summer fishing, nets were set in the evening, weather permitting, and hauled the next morning. The basic INPFC string (see p. 125) of 24 gillnets plus additional nets were fished. Additional nets were two 2", four 3 $\frac{1}{8}$ " and ten 4 $\frac{1}{2}$ " in 1962; three 2 $\frac{1}{2}$ ", three 3 $\frac{1}{4}$ " and two 4 $\frac{1}{2}$ " in 1963. Average daily fishing effort was therefore 2,000 fathoms of net in 1962 and 1,600 fathoms in 1963. Gear loss or damage caused some variation.

Shipboard procedures were as in spring and summer cruises. On hauling, fish were enumerated by species, by mesh size, and direction of entry into nets (right or left side). When hauling was completed, lengths (snout to tail fork) were measured and recorded, scale samples taken and sex determined. All fish caught in 1962 were frozen and brought to the laboratory for detailed examination; return of whole specimens to the laboratory was discontinued in 1963.

BASIC CATCH DATA

Table 12 gives catch data by species and mesh size.

DISTRIBUTION AND RELATIVE ABUNDANCE

Figures 11, 12 and 13 show catches of sockeye and chum salmon per 100 fathoms of net. In Figure 11, catches of one-winter-at-sea sockeye in 2" and 2 $\frac{1}{2}$ " mesh nets are shown; in Figure 12, catches of two, three and four-winter-at-sea sockeye in larger meshes; and in Figure 13, catches of chum salmon three to seven years old, also in the larger mesh sizes.

Juvenile sockeye were taken further south in the Bering Sea than older sockeye; south of the Aleutian Islands, the apparent distribution of juvenile and older sockeye was similar. In the Gulf of Alaska, juveniles were concentrated between latitudes 48° and 52°N. during the cruise along longitude 155°W. in 1962; in 1963, they were found at three widely separated stations along longitude 165°W.

A single juvenile chum salmon (not illustrated) was taken at latitude 47°N. and longitude 155°W. in 1962. In the areas covered in both years, older chum salmon

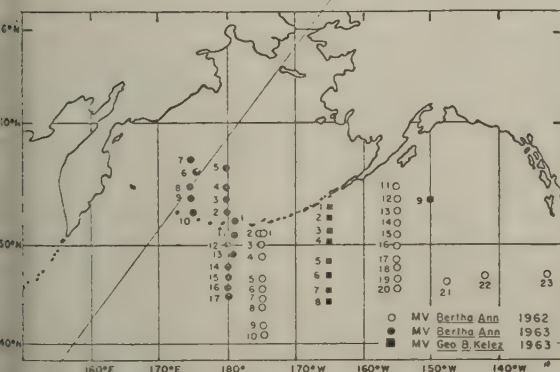


FIGURE 10. Fishing stations of United States research cruises, winter 1962 and 1963.

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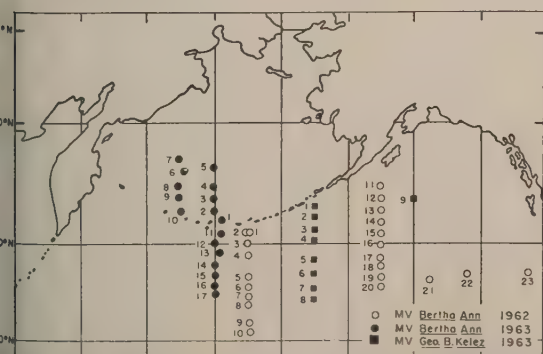


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Shipboard procedures were as in spring and summer cruises. On hauling, fish were enumerated by species, by mesh size, and direction of entry into nets (right or left side). When hauling was completed, lengths (snout to tail fork) were measured and recorded, scale samples taken and sex determined. All fish caught in 1962 were frozen and brought to the laboratory for detailed examination; return of whole specimens to the laboratory was discontinued in 1963.

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A single juvenile chum salmon (not illustrated) was taken at latitude 47°N. and longitude 155°W. in 1962. In the areas covered in both years, older chum salmon

TABLE 12. Salmon catches by United States

MV *Bertha Ann*—WINTER CRUISE—1962.

Set no.	Date	Position		Surf. temp. °C.	No. of shackles	Sockeye					
						Mesh size					2
		Lat. N.	Longitude			5½	4½	3½	3¼	2½	
1	2/10	51°03'	174°56'W.	3.8	33	2	15	1	1	1	2
2	2/19	51°00'	175°02'W.	3.5	40	2	47	8	0	1	1
3	2/21	50°00'	175°00'W.	3.6	31	0	39	6	3	4	8
4	2/25	49°00'	175°00'W.	4.2	37	1	38	6	0	0	0
5	2/27	47°00'	175°00'W.	4.8	28	0	6	1	1	1	0
6	3/1	46°00'	175°00'W.	5.9	36	0	0	0	0	0	0
7	3/2	45°00'	175°00'W.	6.0	38	0	0	0	0	0	0
8	3/3	44°00'	175°00'W.	8.9	38	0	0	0	0	0	0
9	3/5	42°00'	175°00'W.	10.2	38	0	0	0	0	0	0
10	3/6	41°00'	175°00'W.	10.9	38	0	0	0	0	0	0
11	3/19	55°00'	155°00'W.	3.9	40	1	8	0	0	0	0
12	3/20	54°00'	155°00'W.	4.0	40	4	15	0	0	0	0
13	3/22	53°00'	155°00'W.	3.8	40	19	137	14	1	1	3
14	3/24	52°00'	155°00'W.	4.0	40	1	11	0	0	0	1
15	3/25	51°00'	155°00'W.	4.6	40	4	169	18	1	1	5
16	3/26	50°00'	155°00'W.	5.0	40	1	47	14	0	8	4
17	3/28	49°00'	155°00'W.	5.5	40	0	39	11	7	3	3
18	3/29	48°00'	155°00'W.	6.0	40	0	9	8	2	1	0
19	3/30	47°00'	155°00'W.	6.8	40	0	8	6	4	1	0
20	4/1	46°00'	155°00'W.	7.0	40	0	0	0	0	0	0
21	4/4	46°25'	147°46'W.	7.8	40	0	0	0	0	0	0
22	4/6	46°54'	142°15'W.	7.6	40	0	1	1	2	0	0
23	4/9	47°43'	133°01'W.	8.0	40	0	0	0	0	0	0
Totals					877	35	589	94	22	22	27

Note: Three sockeye were taken in 2-inch monofilament nets fished in sets number 12 and 13.

MV *Bertha Ann*—WINTER CRUISE—1963.

Set no.	Date	Position		Surf. temp. °C.	No. of shackles	Sockeye				
						Mesh size				2
		Lat. N.	Longitude			5½	4½	3½	2½	
1	1/28	52°40'	179°21'W.	3.8	30	2	12	7	2	0
2	1/29	53°27'	179°53'E.	3.5	30	4	22	4	4	0
3	1/30	54°34'	179°55'E.	3.0	22	1	3	2	0	0
4	2/1	55°30'	179°58'E.	3.0	32	3	33	0	0	0
5	2/2	56°32'	179°43'E.	2.9	30	2	11	2	0	0
6	2/4	56°25'	175°28'E.	2.7	32	10	67	0	1	0
7	2/5	57°28'	175°00'E.	2.4	32	11	26	1	0	0
8	2/6	55°29'	174°50'E.	2.7	32	9	28	0	0	0
9	2/7	54°26'	174°57'E.	3.2	32	3	9	0	5	0
10	2/8	53°28'	175°14'E.	3.4	32	6	10	1	7	0
11	2/16	50°52'	179°31'W.	3.4	31	7	38	1	7	0
12	2/17	49°57'	179°56'W.	3.7	32	2	9	0	7	0
13	2/18	48°57'	179°45'W.	3.8	32	5	27	0	2	0
14	2/19	47°56'	180°00'	4.5	30	1	7	0	6	0
15	2/20	46°58'	179°55'E.	4.2	31	0	4	6	1	0
16	2/21	45°55'	180°00'	6.0	32	0	2	12	0	0
17	2/22	45°02'	179°57'E.	7.2	32	0	0	0	0	0
Totals					524	66	308	36	42	0

research vessels during the winter cruises in 1962-1963.

Chum							Pink							Total salmon catch			Steel- head
Mesh size						Mesh size											
5½	4½	3½	3¼	2½	2	Total	5½	4½	3½	3¼	2½	2	Total				
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	0
0	2	0	0	0	0	2	0	0	0	0	1	0	1	0	0	62	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	60	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	45	0
0	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	11	0
0	3	2	0	0	0	5	0	0	0	0	0	0	0	1	0	6	0
0	8	1	0	0	1	10	0	0	0	0	12	0	12	4	1	27	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0
2	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	179	0
0	4	0	0	0	0	4	0	0	0	0	0	0	0	0	0	17	0
0	3	0	0	0	0	3	0	0	0	0	0	0	0	0	0	201	0
0	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	76	0
2	20	0	1	0	0	23	0	0	0	1	0	0	1	0	0	87	0
3	27	4	0	0	0	34	0	0	0	0	0	0	0	0	0	54	0
1	34	5	2	0	1	43	0	0	0	0	1	0	1	6	0	6	0
1	12	0	0	0	0	13	0	0	0	0	0	0	0	14	0	14	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	9	0	1	0	0	11	0	0	0	0	0	0	0	8	0	23	4
0	7	1	0	0	0	8	0	0	0	0	0	0	0	8	0	16	2
10	133	13	4	0	2	162	0	0	0	1	14	0	15	41	1	935	6

Continued.

Chum						Pink									Total salmon catch	Steel- head
Mesh size					Total	Mesh size					Total	Coho	Chinook			
5½	4½	3½	2½	2		5½	4½	3½	2½	2						
0	0	0	0	0	0	0	0	0	0	0	0	0	0	23	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	34	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	36	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	78	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	38	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	37	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	0	
0	2	0	0	0	2	0	0	0	0	0	0	0	0	26	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	53	0	
0	0	0	0	0	0	0	0	0	3	0	3	0	1	22	0	
2	17	0	0	0	19	0	0	0	0	0	0	0	0	53	0	
1	4	0	0	0	5	0	0	0	0	0	0	0	0	19	0	
4	18	2	0	0	24	0	0	0	0	0	0	0	0	35	0	
3	7	2	0	0	12	0	0	0	0	0	0	2	0	28	0	
2	0	0	0	0	2	0	0	0	1	0	1	0	0	3	0	
12	48	4	0	0	64	0	0	0	4	0	4	2	1	523	0	

MV *George B. Kelez*—WINTER CRUISE—1963.

Set no.	Date	Position		Surf temp. °C.	No. of shackles	Sockeye			
		Lat. N.	Longitude			Mesh size			
						5½	4½	3½	2½
1	2/11	53°30'	165°00'W.	3.8	32	2	5	0	1
2	2/12	52°30'	165°00'W.	3.4	32	0	3	0	0
3	2/14	51°30'	165°00'W.	3.6	31	2	7	0	0
4	2/16	50°30'	165°00'W.	3.8	32	6	11	1	1
5	2/19	49°00'	165°02'W.	4.8	32	3	10	1	0
6	2/20	47°30'	165°00'W.	5.8	32	0	1	1	11
7	2/22	45°48'	165°00'W.	7.0	32	0	0	0	0
8	2/23	44°30'	165°00'W.	8.4	32	0	0	0	0
9	3/7	54°00'	150°00'W.	3.7	2	0	0	0	0
Totals					257	13	37	3	13

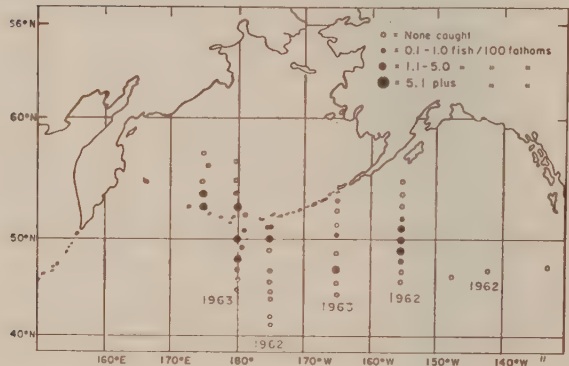


FIGURE 11. Relative abundance of one-winter-at-sea sockeye salmon taken in 2" and 2½" mesh nets, winter cruises 1962 and 1963.

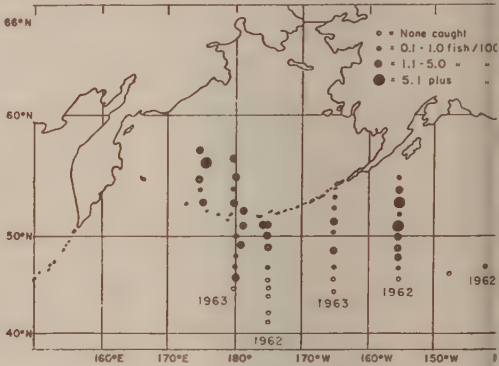


FIGURE 12. Relative abundance of two-, three- and four-winter-at-sea sockeye salmon taken in 3½", 3⅞", 4½" and 5½" mesh nets, winter cruises 1962 and 1963.

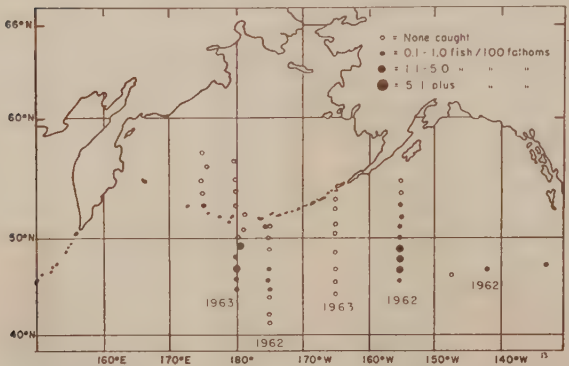


FIGURE 13. Relative abundance of three-, four-, five-, six- and seven-year-old chum salmon taken in 3½", 3⅞", 4½" and 5½" mesh nets, winter cruises 1962 and 1963.

were relatively more abundant between latitudes 47° and 49° N. and along longitudes 155°W. and 180°.

The small pink, coho, and chinook salmon given in Table 12 (not illustrated) were made ge between latitudes 45°N. and 50°N.

Winter and summer abundance can be con in certain areas fished at both times of the South of the Aleutian Islands, fewer older s were taken in winter cruises of both 1962 and than were present as immatures during the pre summers of 1961 and 1962 (French, 1963; 1964 the Gulf of Alaska, however, winter sockeye c along longitude 155°W. substantially exceeded in the summer of 1961.

Catches of chum salmon were generally lo winter than summer.

AGE COMPOSITION

All salmon caught in winter are given a bi

Continued.

Chums	Pink				Total	Coho	Chinook	Total salmon catch	Steelhead
	Mesh size								
	5¼	4½	3¼	2½					
0	0	0	0	0	0	0	0	8	0
0	0	0	0	0	0	0	0	3	0
0	0	0	0	0	0	0	0	9	0
0	0	0	0	0	0	0	0	19	0
0	0	0	0	8	8	6	0	22	0
0	0	0	0	3	3	3	0	22	0
0	0	0	0	2	2	0	0	5	1
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	13	13	9	0	88	1

TABLE 13. Age composition of sockeye salmon taken during the winter cruises, 1962-1963.

Vessel and area	Set no.	1-winter-at-sea				2-winter-at-sea					3-winter-at-sea					4-winter-at-sea		No age data	Total
		3 ₂	4 ₃	5 ₄	Not read*	3 ₁	4 ₂	5 ₃	6 ₄	Not read*	4 ₁	5 ₂	6 ₃	7 ₄	Not read*	6 ₂	Not read*		
1962																			
<i>Bertha Ann</i>																			
Aleutian	1		3				1	7		1		3	6			1		22	
	2	1	1				1	25				13	10	1	1			6	59
	3	3	3	1	4		4	16	1			8	10	1				6	57
	4						1	24		1		7	7	1				4	45
	5		1				1	3				3						1	9
Totals		4	8	1	4		8	75	1	2		34	33	3	1	1		17	192
Per cent																			
(known ages)		2.3	4.7	0.6			4.7	44.6	0.6			20.2	19.6	1.8		0.6			(168)
Per cent																			
(ocean age)			9.7					49.1					40.6			0.6			(175)
<i>Bertha Ann</i>																			
Gulf of Alaska	11						2	1				5	1						9
	12							1				13	4	1	1				20
	13						22	30	3	1	1	51	62	3		1		3	177
	14				1		2	5				2	3						13
	15	4			1		48	75	1	2		36	26	2				2	197
	16	6	5		1		14	31	4			6	7						74
	17	4	1		1		9	33	5			7	1	1				1	63
	18	1					7	9		1		2							20
	19		2				9	8											19
	22						3	1											4
Totals		15	8		4		116	194	13	4	1	122	104	7	1	1		6	596
Per cent																			
(known ages)		2.6	1.4				20.0	33.4	2.2		0.2	21.0	17.9	1.2		0.2			(581)
Per cent																			
(ocean age)			4.6					55.4					39.8			0.2			(590)

Continued...

TABLE 13. Continued.

Vessel and area	Set no.	1-winter-at-sea				2-winter-at-sea				3-winter-at-sea					4-winter-at-sea			No age data
		3 ₂	4 ₃	5 ₄	Not read*	3 ₁	4 ₂	5 ₃	6 ₄	Not read*	4 ₁	5 ₂	6 ₃	7 ₄	Not read*	6 ₂	Not read*	
1963																		
Bertha Ann																		
Aleutian	1		1	1	1		2	7	1			1	5	2				1
	2	1	2	1			4	10	1	2	1	2	7	1			2	
	3		1				1					2	2					
	4						2	4	1	2		9	14	2	2			
	5						1	1				2	7		1			3
	6		1				1	7	1		1	28	30	4	4			1
	7							2				9	18	4	3	2		
	8							3	1			17	10	2	2			2
	9	2	3					1				7	3	1				
	10	4	3				3	3	1		1	2	6					1
	11	2	2				1	1			1	17	24	1	2	1		1
	12	1	4		1		2	1				5	4					
	13		1	1				5				12	11		3			1
	14	1	4	1				5				2						1
	15		1					5	4	1								
	16					2	7	4				1						
Totals		11	23	4	2	2	29	58	7	4	4	116	141	17	17	3	2	11
Per cent																		
(known ages)		2.7	5.5	1.0		0.5	7.0	14.0	1.7		1.0	28.0	34.0	4.1		0.7		
Per cent																		
(ocean age)			9.1				22.7					67.0				1.1		
George B.																		
Kelez																		
Gulf of Alaska	1		1									4	2					1
	2										1	1						1
	3						1	2				4	2					
	4	1					4	1				4	1		1		1	6
	5						1	1				6	6					
	6	2	3	1			2											5
Totals		3	4	1			8	4			1	19	11		1		1	13
Per cent																		
(known ages)		5.9	7.8	2.0			15.7	7.8			2.0	37.3	21.6					
Per cent																		
(ocean age)			15.1				22.6				60.4					1.9		

* Ocean ages only were determined from these scales.

January 1 even though the current ocean annulus on the scale may not be complete that early in the year. Therefore, a fish taken in winter is assigned the same age as if taken in the following spring or summer.

Sockeye Salmon

Figures 14 through 17 show length frequencies of sockeye by number of winters at sea. Capture of juveniles below 250 mm. fork length in 1962 but not in 1963 is undoubtedly due to use of 2" mesh in 1962 only; this probably explains the left-skewed length

frequency distribution of juveniles taken in the Aleutian Islands area in 1963. Bimodality shown on two-winter sockeye, Aleutian area 1963 (Fig. 13) of interest. Possibly significant numbers of two-winter fish were more abundant this year than in areas fished in 1962 and in the Gulf of Alaska.

Table 13 gives the age composition of sockeye. 1962 catches of two-winter-at-sea fish predominate and the age 5₃ group was most common in both Aleutian Islands and Gulf of Alaska areas.

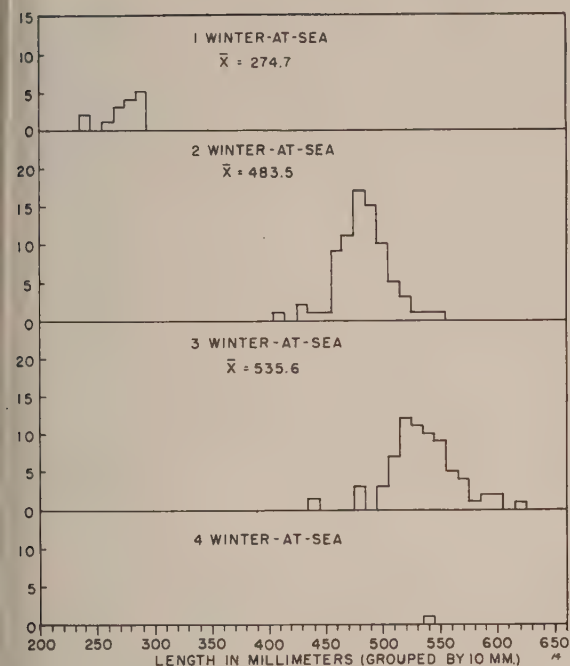


FIGURE 14. Length frequency distribution of sockeye salmon by ocean-winter age, Aleutian Island area, winter 1962.

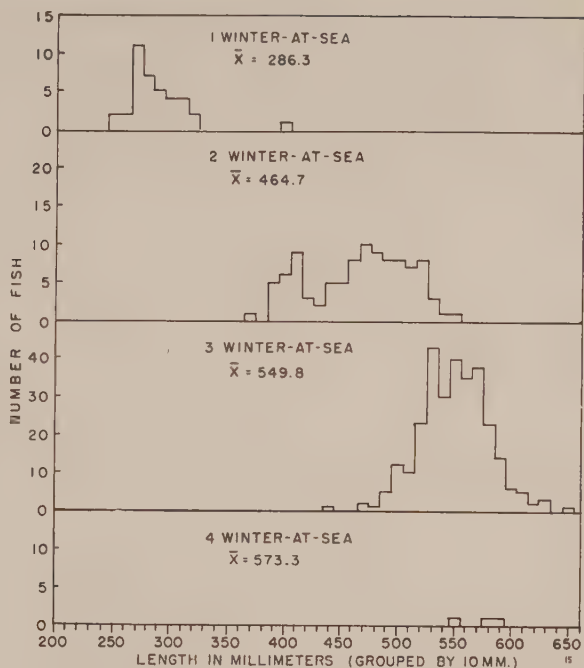


FIGURE 15. Length frequency distribution of sockeye salmon by ocean-winter age, Aleutian Island area, winter 1963.

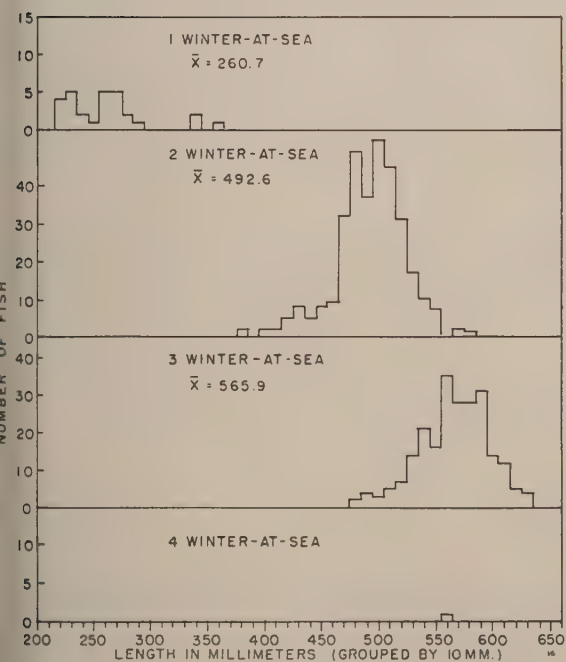


FIGURE 16. Length frequency distribution of sockeye salmon by ocean-winter age, Gulf of Alaska area, winter 1962.

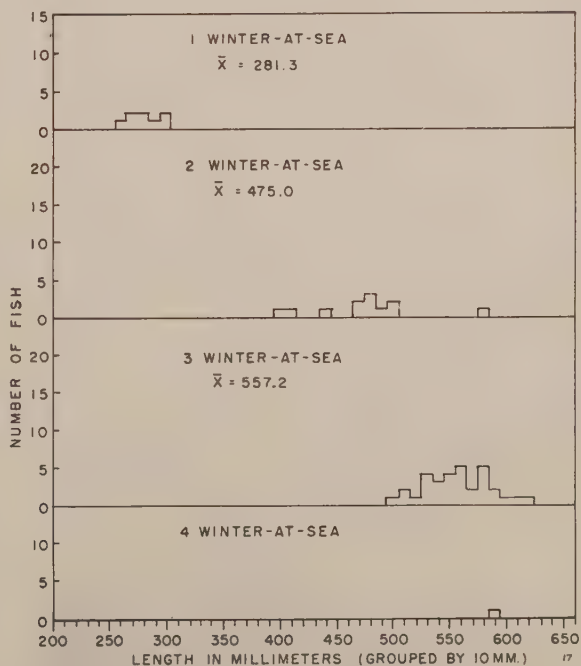


FIGURE 17. Length frequency distribution of sockeye salmon by ocean-winter age, Gulf of Alaska area, winter 1963.

and 6₃ were about equally represented in the less abundant three-winter-at-sea fish. In 1963 catches, on the other hand, three-winter-at-sea fish predominated among older sockeye; occurrence of ages 5₂ and 6₃ was nearly equal in both fishing areas. In

the Aleutian Islands area, age 5₃ predominated, less common two-winter-at-sea fish in 1963, 4₂ occurred more frequently in the Gulf of Alaska. Proportions of sockeye within each ocean area were quite consistent from set to set in both years.

TABLE 14. Average lengths (mm.) of winter-caught sockeye salmon, by age groups and sex, 1962 and 1963, areas of origin (numbers in sample).

Year	One-winter-at-sea				Two-winter-at-sea						Three-winter-at-sea					
	3 ₂		4 ₃		4 ₂		5 ₃		6 ₄		5 ₂		6 ₃		7 ₄	
	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
1962	254 (9)	242 (8)	289 (7)	268 (7)	493 (66)	485 (57)	491 (141)	479 (119)	511 (12)	498 (3)	569 (66)	544 (81)	579 (56)	555 (75)	571 (3)	557 (3)
1963	270 (7)	278 (4)	293 (15)	289 (11)	461 (19)	430 (15)	485 (35)	466 (22)	458 (3)	485 (4)	567 (57)	536 (74)	568 (59)	540 (87)	540 (3)	540 (3)

TABLE 15. Age composition of chum salmon taken during winter cruises, 1962-1963.

		Age							
	Set No.	2	3	4	5	6	7	No data	
1962									
<i>Bertha Ann</i>									
Aleutian	2			1			1		
	5				2				
	6			2	3				
	7		1	3	5			1	
Totals			1	6	10		1	1	
Per cent			5.3	31.6	52.6		5.3	5.3	
<i>Bertha Ann</i>									
Gulf of Alaska	13			1	1				
	14			2	2				
	15			1	2				
	16			1	1				
	17			9	14				
	18		2	18	13	1			
	19	1	3	21	17	1			
	20			6	7				
	22			9	1			1	
	23		5	2	1				
Totals		1	10	70	59	2		1	
Per cent		0.7	7.0	49.0	41.3	1.4		0.7	
1963									
<i>Bertha Ann</i>									
Aleutian	10			1	1				
	13			6	12	1			
	14			3	2				
	15		1	17	5			1	
	16			10	2				
	17			2					
Totals			1	39	22	1		1	
Per cent			1.6	60.9	34.4	1.6		1.6	

Table 14 gives average lengths of sockeye by age, with catches from both fishing areas combined. Of the one-winter-at-sea fish, average length was greater for the 4₃ than for the 3₂ group. Of the two-winter-at-sea fish, 4₂ sockeye were nearly the same size as 5₃ sockeye in 1962, but smaller in 1963. Average lengths of the 5₂ and 6₃ groups of three-winter-at-sea sockeye were approximately equal both years. Males were larger on the average than females; exceptions occurred only when the samples were quite small.

Both sexes were about equally represented in catches of one-winter-at-sea sockeye. Males outnumbered females, except in a single small sample, among two-winter-at-sea fish. Finally, females dominated each freshwater age group of three-winter-at-sea sockeye.

Chum Salmon

Low catches of chum salmon prevent meaningful comparisons of size by age groups. Table 15 shows that age 4 was the most common in the Aleutian Islands area in 1963 and in the Gulf of Alaska in 1962. Age 5 dominated the very small sample taken from the former area in 1962. Only one chum salmon in its second year was taken on these winter cruises. This could be due either to a differential age distribution or to the fact that even 2" or 2½" mesh is too large to retain such small fish.

Pink Salmon

The pink salmon caught ranged in size from 288 to 379 mm. A sample of 27 fish contained 21 males.

Coho Salmon

Coho salmon ranged in size from 340 to 551 mm.; modes occurred at 350 and 480 mm. in the length frequency distribution of the 52 fish taken on the winter cruises. Of these 52, 29 were males.

Chinook Salmon

The two chinook salmon caught, both females, were 522 and 650 mm. long.

MATURITY

Sockeye Salmon

The onset of maturity was demonstrated for some 1963 winter sockeye by serological methods (Ridgway *et al.*, 1962). Examinations of 81 female samples for the presence or absence of the sm antigen, unique in maturing females, gave the results shown in Table 16.

TABLE 16. Result of examination of 81 female sockeye salmon for the presence or absence of the sm antigen.

Gonad displacement both ovaries (ml.)	Area and date			
	Bering Sea Jan. 28-Feb.5		North Pacific Feb. 16-21	
	sm antigen		sm antigen	
	+	-	+	-
Less than 5	0	3	0	13
6-10	2	1	2	2
11-15	3	1	1	1
16 and over	31	0	21	0
Totals	36	5	24	16

Histological examinations of gonads also indicated the onset of maturity for some sockeye. (See section on serology elsewhere in this report.)

Spawning runs consist primarily of two and three-winter-at-sea sockeye; therefore, it is reasonably certain that all or most three-winter and a smaller proportion of two-winter fish will mature the following summer. Nearly all one-winter-at-sea sockeye will remain at sea one or more winters before maturing.

Other Salmon

Maturity status of chum and the two chinook salmon was not determined. Chum salmon, however, may mature at any of the six age classes found in winter samples. Life histories of pink and coho salmon indicate they would have matured the following summer or fall.

TEMPERATURE AND SALMON OCCURRENCE

Surface water temperatures encountered during the winter cruises ranged from 2.4°C. in the Bering Sea to 10.9°C. in the North Pacific Ocean. Table 17 gives the occurrence of salmon in different surface temperatures. Sockeye salmon occurred more in colder water; pink and coho, in warmer waters. Chum salmon were not taken in the coldest waters, but otherwise occurred throughout the range of surface temperature. No statement is possible for the two chinook salmon.

CATCHES OF OTHER SPECIES

Larkins (1963) reported 37 non-salmon species during spring and summer. Winter conditions in these waters evidently reduce the number of species and abundance of each. Catches of two elasmobranch and three teleost species were as follows: 43 mackerel (salmon) sharks (*Lamna ditropis*); one bask-

TABLE 17. Surface temperatures and number of gillnet sets taking salmon, winter cruises, 1962-1963.

Aleutian Island area										Gulf of Alaska area (E. of 165° W.)						
Sockeye					Chum					Sockeye					Chum	
Temper- ature (°C.)	No. of sets	1- winter- at-sea	2, 3- winter- at-sea	2- year- old	3-6 year- old	Pink	Coho	Chi- nook		No. of sets	1- winter- at-sea	2, 3- winter- at-sea	2- year- old	3-6 year- old	Pink	Coho
2.0-2.9	4	1	4							0						
3.0-3.9	12	11	12		3	2		1		6	2	4		1		
4.0-4.9	4	3	4		3					4		1		1		
5.0-5.9	1				1	1	2			3	1	1		1	1	1
6.0-6.9	2		1		2	2	2	1		2			1	2	1	1
7.0-7.9	1				1	1	3			4				2		3
8.0-8.9	1						1			2				1		1
9.0-9.9	0									0						
10.0-10.9	2									0						

ing shark (*Cetorhinus maximus*); seven steelhead (*Salmo gairdneri*); one blackcod (*Anoplopoma fimbria*); and one threespine stickleback (*Gasterosteus aculeatus*).

Judging from visual observations, bird life, fur seals, sea lions, and whales were much less abundant than during spring or summer.

OPERATIONAL ASPECTS

Northern waters of the North Pacific Ocean and the Bering Sea are difficult areas for research cruises because of generally unfavorable weather. During summer cruises, vessels average about two days per gillnet set (round trip from home port). In the two winter seasons we averaged about one set every 3.5 days. Entire cruise tracks may have to be abandoned if weather continues bad for extended periods, as for example, in 1963 when a planned cruise along longitude 155°W. was given up. On the other hand, that same year ten sets were made in 12 days in the Bering Sea.

Hazardous icing conditions were encountered in the Bering Sea, and the position of ice floes was not known. Therefore, this northward cruise was terminated at latitude 57°28'N. even though salmon were still being taken.

Winter fishing has proven operationally feasible despite the difficulties and dangers. Certainly, direct sampling is the only way to collect these important biological and environmental data.

DISCUSSION

The cruises of 1962 and 1963 provided our first knowledge of the winter distribution of salmon.

Contrary to some earlier beliefs, sockeye were in the Bering Sea in winter, and at least to 57°27'N.

Comparatively large catches of sockeye indicate the Gulf of Alaska to be a major center of abundance. Results of Canadian longline (Neave *et al.*, 1962) support this view. While they took large numbers of sockeye from April to May 6 in the central and north-central Gulf of Alaska. Their best catches from May 10 to May 20 were made 80 to 100 miles east of our own high catches by gillnets in March.

Biological and environmental data collected during these cruises indicate many interesting lines of inquiry; for example, the age composition of sockeye catches from the Gulf of Alaska indicates older fish were further north in the Gulf than young fish. Also, chum salmon were not taken along longitude 165°W. but were elsewhere in the North Pacific and Gulf of Alaska.

Clearly, however, the areas covered during these winter cruises are but a small portion of the Bering Sea and North Pacific Ocean throughout which several species may be distributed in winter. Further study to find even the major centers of winter abundance will require further research.

SUMMARY

Winter research cruises in 1962 and 1963 provided our first knowledge of the winter distribution of salmon catches at nearly all stations fished with gillnets in the Bering Sea, North Pacific Ocean and Gulf of Alaska.

Only sockeye were taken in the Bering Sea during these cruises. For two chum salmon caught just north of the Gulf of Alaska.

Islands, and sockeye was the dominant species generally. Next in relative abundance were chum salmon; relatively few pink, coho and chinook salmon were caught.

Sockeye and chum salmon were broadly distributed along longitudes 180° and 175°W. in the North Pacific. These species occurred along 155°W. between latitudes 46°N. and 54°30'N. in the Gulf of Alaska, but only sockeye were taken along longitude 165°W. Most pink and coho salmon were caught between latitudes 45°N. and 50°N. No salmon were taken south of latitude 45°N.

Catches of salmon in winter were generally less than in summer, although the 1962 winter cruise along longitude 155°W. produced more sockeye than in summer.

In 1962, two-winter-at-sea sockeye were most common; three-winter-at-sea fish were dominant in 1963. The majority of chum salmon both years were age 4. In general, older fish were most common in both species.

Sea surface temperatures ranged from 2.4°C. to 10.9°C., with salmon being taken in waters ranging from 2.4°C. to 8.0°C. Sockeye were taken in colder water than were chum, pink and coho salmon.

The sockeye were both immature and maturing; maturity status of chum salmon was not determined, and pink and coho salmon would have matured the following summer and fall.

Mackerel sharks were the most prevalent of the non-salmon species. Otherwise, the abundance of fish and other sea life was much less than during the summer.

Winter research cruises are operationally feasible, although fewer fishing sets per unit of time can be expected than in spring and summer.

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Isistius plutodus, a New Squaloid Shark from the Gulf of Mexico

J. A. F. GARRICK AND STEWART SPRINGER

Isistius plutodus, a New Squaloid Shark from the Gulf of Mexico

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Isistius plutodus is described from a single specimen differing notably from the only other species of the genus in the larger size and smaller number of the lower jaw teeth (9.1-9), in proportions (smaller tail and paired fins, and larger second dorsal fin), and in the reduced color pattern.

A single specimen of a small, cigar-shaped shark from the Gulf of Mexico is described here as a new species of the squaloid genus *Isistius*. The specimen was collected in a midwater trawl by the M/V OREGON about 100 miles south of Dauphin Island, Alabama.

For comparison with the new species, we have examined 2 series of *Isistius* in the U. S. National Museum. One of these series was collected by the M/V OREGON in the Gulf of Mexico (catalog numbers USNM 188381 to 188385). The other series (USNM 164173 to 164175 and 190033 to 190043), collected by research vessels of the Bureau of Commercial Fisheries, was from the central Pacific Ocean. This Pacific series has been reported in part by King and Ikehara (1956), and subsequently by Strasburg (1963). Garrick surveyed *Isistius* in several European museums.

Examination of the above material has shown that, except for the single specimen

that we describe here as a new species, all the other specimens are referable to *Isistius brasiliensis* (Quoy and Gaimard 1824). Synonyms and references to *I. brasiliensis* are given by Bigelow and Schroeder (1948:513-514, 1957:123-124). We see no indication that these refer to any species other than *I. brasiliensis*. The diagnosis of *I. brasiliensis* var. *unicolor* (Valenciennes in Müller and Henle 1841) approximates that of the new species in regard to color, but examination of the type (MNHN 1178) in the Muséum National d'Histoire Naturelle in Paris clearly reveals that Valenciennes' variety is *brasiliensis*.

Our new species is an addition to the interesting but little known midwater shark fauna. With a few exceptions, the representatives of this fauna have been taken at or near the surface over deep or comparatively deep water, usually during the night, and include four squaloid genera, viz., *Eupr*

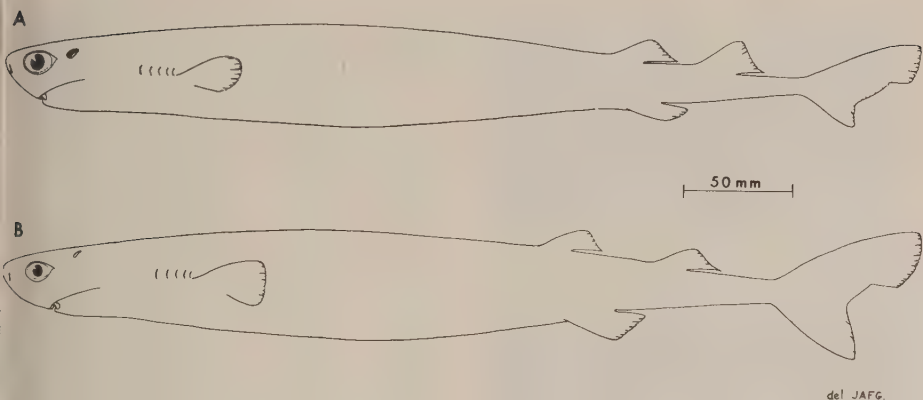


Fig. 1. A, *Isistius plutodus* sp. nov., USNM 188386, 423-mm female, holotype. B, *Isistius brasiliensis* USNM 188382, 426-mm female, M/V OREGON station 2507, near type locality of *I. plutodus*.

tomicrus, *Isistius*, *Squaliolus*, and *Heteroscyrnoides*. The few known specimens of *Euprotomicrus bispinatus* show a wide range in the Pacific and Indian oceans. The rarely taken *Squaliolus laticaudus* and *S. sarmenti* are from the Pacific and Atlantic oceans, respectively, while *Isistius brasiliensis* is found in both oceans.

Isistius plutodus new species

(Figs. 1, 2)

Holotype.—An adult female, 423 mm in total length, USNM 188386, collected at M/V OREGON station 3102, 28°58' N, 88°18' W, off the coast of Alabama, in 60-ft midwater trawl, depth of capture not determined but depth of bottom at place of capture 445 to 545 fathoms.

Diagnosis.—An *Isistius* with the dental formula $\frac{14 + 1 + 14}{9 + 1 + 9}$; with a short caudal

peduncle and small caudal fin, the lower lobe of the latter only half the length of the upper; with the second dorsal fin notably higher than the first; and with no clearly defined black collar and no markings on the caudal fin.

Comparison.—The lower teeth of *Isistius plutodus* (Fig. 2A) are much larger than in *I. brasiliensis* (Fig. 2B). In the specimens of *I. brasiliensis* examined, the lower teeth number 25 to 31 per row, with 12 to 15 teeth on each side of a symphyseal tooth, whereas in *I. plutodus* there are 19 teeth per row with 9 teeth on each side. The upper jaw

teeth of *I. plutodus* are only slightly reduced in number, but are somewhat shorter than the teeth of *I. brasiliensis*. In *I. plutodus* there are 14 + 1 + 14 upper teeth per row, whereas in *I. brasiliensis* the number varies from 15 + 1 + 15 to 18 + 1 + 18, the highest number occurring in a Gulf of Mexico specimen.

The lower caudal lobe is about half the length of the upper caudal lobe in *I. plutodus*, but about two-thirds of it in *I. brasiliensis*. The second dorsal fin is substantially higher (about 1.3 times as high) than the first dorsal fin in *I. plutodus*, but in *I. brasiliensis* the two fins are about the same height. In *I. plutodus* the pectoral and pelvic fins are smaller, the snout somewhat shorter, the prepelvic and predorsal lengths greater, and the interspace between the two dorsal fins, as well as the interspace between the second dorsal and caudal, shorter than in *I. brasiliensis*. *Isistius plutodus* has a much shorter caudal region than *I. brasiliensis*, hence some of the proportions of *I. plutodus* involving caudal measurements are reduced (Table 1). The differences in these caudal proportions probably provide the most reliable means, other than the number of lower teeth, for distinguishing *I. plutodus* from *I. brasiliensis*. The pectoral fin of *I. plutodus* is rounded and translucent at its tip rather than truncate and white-banded as in *I. brasiliensis*. *Isistius plutodus* lacks the clearly defined black collar and the darker coloration at the upper and lower caudal fin tips that characterize most specimens of *I. brasiliensis*. Furthermore, in most specimens



Fig. 2. A and C, *Isistius plutodus* sp. nov., B and D, *Isistius brasiliensis*, showing proportional differences in lower teeth and caudal fin (photographs by Smithsonian Institution).

of *I. brasiliensis* the color contrast between the dorsal and ventral surfaces is much greater than in the type of *I. plutodus*. *Isistius plutodus* has fewer luminescent pits on the abdomen than the specimens of *I. brasiliensis* examined, and has none on the dorsal surface or sides.

Description of holotype.—Head slightly depressed; trunk slender, attenuate posteriorly; caudal peduncle without precaudal pits, but with a weak ventrolateral keel along each side from pelvic axil posteriorly onto anterior portion of caudal axis; caudal fin notably small, caudal axis scarcely raised above a horizontal axis through trunk. Height of trunk at origin of pectorals 8.9 in its length to origin of caudal. Length of trunk anterior to cloaca 70.7% of total length.

Head measured to fifth gill opening 4.6 in length to origin of caudal. Snout fleshy, foreshortened, bluntly tapering in profile, its

length in front of mouth (tip of snout to anterior edge of denticle-covered portion of upper lip) a little more than one-fifth of head length. Eye oval, longer than high, its horizontal diameter about equal to preopercular length. Spiracles large, oblique, opening dorsolaterally above and behind eyes, oval wider than long, their width about half horizontal diameter of eye. Gill opening minute, vertical, concave posteriorly, their lengths subequal, equivalent to one-fourth of horizontal eye diameter or less; fifth gill openings slightly in front of pectoral origins. Nostrils small, oblique, placed just below and very close to tip of snout; anterior margin of each nostril expanded into a low pointed lobe. Mouth almost transverse, its lower lip fleshy and smooth, its angles enclosed by a prominent labial fold on each side. Upper lip divisible into an outer (anterior) denticle-covered portion which overlies an inner fleshy portion; when mouth is closed its angles mostly concealed by smooth curved, outer upper lip which extends posterolaterally on each side to a little behind a vertical through spiracles.

Dermal denticles small, sessile, quadrate in outline, closely packed but their bases not touching, their low crowns truncate in side view, hollowed out above, and with concave margins.

Dental formula $\frac{14 + 1 + 14}{9 + 1 + 9}$. Upper teeth

very small, smooth-edged, narrowly triangular, almost straight and symmetrical at center of mouth but slightly oblique or curved towards sides; 2 or 3 rows of upper teeth functional. Lower teeth extremely large, with high rectangular bases and broadly triangular cusps; those at center of mouth with cusps erect and symmetrical; those towards sides slightly and increasingly oblique with their points directed medially (i.e., towards center of mouth) rather than laterally (the oblique cusps of the upper teeth point laterally); margins of lower teeth minutely serrated, slightly sinuous, and separated from bases of teeth by a weak shoulder on each side; base of median lower tooth overlapping its neighbor on each side, and each subsequent tooth overlapping the next lateral one; one row of lower teeth functional.

First dorsal fin small, placed far back (the distance from snout tip to first dorsal origin almost two-thirds of total length, posterior third of its base situated over pelvic

TABLE 1. DIMENSIONS OF *Isistius* AS PER CENT OF TOTAL LENGTH (MEASUREMENTS MADE AS DESCRIBED IN BIGELOW AND SCHROEDER 1948:61). Differences especially noticeable in measurements marked with an asterisk *.

	<i>Isistius plutodus</i>		<i>Isistius brasiliensis</i>				
	Gulf of Mexico		Gulf of Mexico			Pacific Ocean	
	423 mm (♀) USNM 188386	351 mm (♂) USNM 188383	389 mm (♂) USNM 188383	416 mm (♀) USNM 188385	426 mm (♀) USNM 188382	335 mm (♂) USNM 190039	358 mm (♀) USNM 190034
total Length in Millimeters →							
Sex →							
Specimen Number →							
snout at pectoral origin:							
width	9.8	10.8	11.6	10.8	11.7	11.3	11.7
height	9.7	9.8	9.8	9.4	9.9	10.1	10.6
tip of snout to:							
outer corners of nostrils	0.6	0.7	0.7	0.5	0.7	0.6	0.6
eye	2.1	2.8	2.7	2.6	2.8	2.6	3.0
spiracle*	7.1	8.4	8.4	8.4	8.2	8.3	8.1
mouth*	4.0	5.7	5.9	5.8	5.6	6.3	5.5
first gill opening	15.1	16.1	16.8	16.1	17.1	17.0	16.1
fifth gill opening	18.7	20.2	20.6	20.2	20.8	20.9	20.0
pectoral origin	19.2	20.5	20.8	20.2	21.1	21.2	20.4
pelvic origin*	68.1	61.3	60.9	63.2	61.0	62.4	60.6
first dorsal origin*	64.6	59.0	59.1	61.1	58.7	59.7	59.8
second dorsal origin*	75.4	71.2	71.7	71.9	70.9	71.6	70.7
upper caudal origin	86.3	86.0	85.1	86.1	84.0	85.4	85.2
lower caudal origin	86.8	85.5	85.1	85.8	83.6	85.1	84.9
distance between bases:							
first and second dorsal*	5.7	8.8	9.3	7.5	9.0	9.3	7.5
second dorsal and caudal*	6.4	11.0	10.3	10.6	9.3	10.1	11.2
pectoral and pelvic*	45.4	37.9	36.2	40.1	35.9	37.9	35.2
pelvic and caudal*	14.7	18.8	18.5	16.9	17.6	18.2	19.0
first dorsal fin:							
length base*	5.6	3.3	3.1	3.6	3.3	3.0	3.0
length posterior margin	3.5	4.0	3.7	3.6	3.4	3.6	3.4
height*	2.8	2.2	2.2	2.3	2.2	2.4	2.2
second dorsal fin:							
length base*	4.5	3.8	3.3	3.9	3.6	3.6	3.9
length posterior margin*	2.8	4.1	3.6	3.7	3.8	4.0	3.4
height*	3.7	2.2	2.2	2.4	2.3	2.4	2.4
pectoral fin:							
length base*	2.5	3.5	4.0	3.6	3.9	3.7	3.6
length anterior margin	7.3	8.0	7.8	7.7	8.1	8.2	7.8
width*	3.6	4.7	5.0	4.9	4.6	5.7	4.6
pelvic fin:							
overall length*	7.0	9.3	9.5	8.7	9.3	8.2	8.3
length base*	3.7	4.8	5.7	5.5	5.9	4.5	5.6
length claspers	—	5.3	6.4	—	—	3.9	—
caudal fin:							
length dorsal lobe	14.4	15.5	15.5	14.8	16.1	15.1	15.6
length ventral lobe	7.1	10.7	10.8	10.3	10.9	11.2	10.8
nostrils:							
distance between inner corners	1.5	1.2	1.3	1.4	1.6	1.3	1.3
length first gill opening	0.9	0.9	1.2	1.0	1.1	1.1	1.0
length fifth gill opening	0.7	0.9	0.9	0.9	0.8	0.7	0.8
horizontal diameter of eye	3.7	3.6	3.3	3.8	3.3	3.6	3.5
vertical diameter of eye	2.6	2.5	2.6	2.6	2.2	2.4	2.5
number precaudal vertebrae	65	—	—	66	62	60	—
number caudal vertebrae	27	—	—	23	20	24	—
total number vertebrae	92	—	—	89	82	84	—

base; height of first dorsal about three-fourths length of its rear tip (posterior lobe), and the latter just less than length of eye; apex of first dorsal smoothly rounded, margins almost straight, rear tip sharply pointed. Second dorsal fin 1.3 times height of first dorsal; apex of second dorsal a little more abruptly rounded than that of first dorsal, anterior margin more strongly convex near apex, its origin over rear tips of pelvic fins; distance between first and second dorsal bases noticeably shorter than that between second dorsal and caudal, and a little greater than length of first dorsal base. Caudal fin remarkably short, less than one-seventh of total length, upper lobe well developed as compared to lower lobe; length of lower lobe only half that of upper lobe; terminal part of upper lobe strong, more or less truncate, with a definite subterminal notch; lower lobe triangular, its tip abruptly rounded. Pelvic fins small, with broadly rounded margins without well-defined anterior (outer) corners. Pectoral fins placed comparatively high on sides of trunk, their origins behind lower ends of fifth gill openings; broadly ovate in shape, their corners and distal margins so strongly convex as to form a continuous curve, their length about twice their greatest width and equal to prepiracular length.

Color in alcohol uniform dark brown above and below except for a paler brown band on underside of head from mouth to gill openings; no conspicuous darker areas through upper side of head and greater part of caudal fin as well as distal half (but not the distal margin) of underside of pelvic fins slightly darker than body; distal margins of all fins pale to translucent; black pits, presumably luminescent, restricted to lower abdominal surface and sparse.

Vertebrae, 65 precaudal, + 27 caudal; cen-

tra elongate, their lengths greater than their diameters; longest centra at posterior end of abdomen; diplospondyly beginning at level of posterior end of pelvic base.

Length	of penultimate mono-	
Diameter	spondylous centrum	= 1.8
Length of penultimate mono-		
spondylous centrum		
Length of first diplospondylous		
centrum		= 1.6

Derivation of name.—The name *plutodus* suggested by Dr. G. S. Myers, is a latinized compound of 2 Greek nouns: the first part *pluto* = Greek *ploutos*, masculine, meaning wealth, riches, abundance; the second part *odus* = Greek *odon* (odon), masculine meaning tooth.

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DIVISION OF FISHES, UNITED STATES NATIONAL MUSEUM, WASHINGTON, D. C., PRESENT ADDRESSES: DEPARTMENT OF ZOOLOGY, VICTORIA UNIVERSITY OF WELLINGTON, WELLINGTON, NEW ZEALAND, AND U. S. BUREAU OF COMMERCIAL FISHERIES, STANFORD, CALIFORNIA.

26. OBSERVATIONS OF FISH FROM A FLOATING
OBSERVATION RAFT AT SEA

Pelagic fishes are frequently seen congregating around floating objects at sea. The ecology and behavior of fish accumulating around a drifting raft with a viewing chamber were observed near the island of Hawaii for a total of 85 daylight hours during five drifts of up to 50 hours' duration. A modified version of this raft was taken south to the Equator where two drifts of 8 and 9 days were made.

Nineteen identified species of fish and one species of porpoise were seen from the chamber near Hawaii. They were classified into three groups—transients, visitors and residents—on the basis of their reaction to the raft and the length of time they remained. Transients included *Decapterus* sp., *Euthynnus pelamis*, and istiophorids; they demonstrated no apparent attraction to the raft. Visitors included *Sphyræna barracuda*, *Pterolamiops longimanus*, *Manta alfredi*, and porpoise. They came to the raft and swam around for a few minutes before leaving. Residents included *Canthidermis maculatus*, *Coryphaena hippurus*, *Prenes cyanophrys*, *Acanthocybium solandri*, *Decapterus* sp., *Seriola* sp. and juvenile *Abudefduf abdominalis*. *P. cyanophrys* was the first to appear on all drifts and had the highest rate of increase.

Total numbers of residents increased three times faster when the raft was drifting than when it was anchored and ten times faster during daylight than at night. *Seriola* sp. was the only predator at the raft which successfully preyed on smaller fishes present. *C. maculatus*, *P. cyanophrys*, *A. abdominalis*, and *Caranx kalla* took shelter near the raft when they were frightened by other fish, approaching boats, or other disturbances. Observations of a *C. maculatus* picking a parasitic isopod from another and attempting to pick from *C. hippurus* and *Decapterus* indicate that apparently *C. maculatus* is a parasite picker and that floating objects may be pelagic cleaning stations.

On the two drifts near the Equator the following animals were seen from the observation chamber: adult and juvenile *E. pelamis*, small adult and juvenile *Neothunnus macropterus*, *A. solandri*, adult *C. hippurus*, adult and juvenile *Coryphaena equiselis*, *Decapterus pinnulatus*, *Elagatis bipinnulatus*, *Prenes cyanophrys*, *P. longimanus*, *Prionace glauca*, *Rhincodon typus*, *Manta* sp., *Naukrates ductor*, *Remora* sp., *Exocoetidae*, turtle and porpoise.

In general, accumulations at the raft had properties ascribed to a community with species playing different interwoven roles.

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U. S. Bureau of Commercial Fisheries

tolerated. Mice inoculated intravenously tolerated 1, 2, and 3 g/kg and showed no gross pathology upon sacrifice.

Paolin 1 inhibited the *in vitro* growth of gram positive as well as gram negative organisms such as *Staphylococcus aureus*, *Streptococcus pyogenes*, beta-hemolytic strain, *Salmonella typhosa*, *Shigella dysenteriae*, etc. at a concentration varying from 4 to 100 ug/ml. Its *in vivo* activity against *S. pyogenes* is illustrated by the following typical experiment. A group of 50 Swiss white mice were fed with oyster extract for 2 weeks using a daily dose of 0.1 g/kg of body weight. Three days after the first feeding these mice, along with 50 controls, were challenged intraperitoneally with a sublethal dose of *S. pyogenes* beta-hemolytic strain. Although about 60% of mice in either group developed abscesses, the death rate at the end of 50 days was 36% for the controls and 10% for the treated animals. Paolin 1 was also prepared in a more purified form by chloroform extraction and Reinecke salt precipitation. The purified material inhibited the growth of *S. aureus in vitro* at a concentration of 1 ppm.

Paolin 2 inhibited poliovirus, type 1, in tissue cultures and in mice. In tissue cultures, paolin 2 was not toxic for primary monkey kidney monolayer culture cells at a concentration of 100-500 ug/ml and did not inactivate poliovirus in absence of living cells. However, it interfered with multiplication of the virus when incorporated in the medium, reducing virus yield by 1 or 2 logarithmic units. When Swiss white mice were fed for 3 days with oyster extract in a daily dose of 0.5 g/kg of body weight starting 24 hours before intracerebral infection with type 1 poliovirus, the death rate of the treated mice was about 25% to 50% lower than that of the controls. After further purification by alcohol fractionation, paolin 2 in a single intra-peritoneal dose of 2.5 mg/kg of body weight, given 5 hours before intracerebral infection with type 1 poliovirus, reduced the death rate from 53% in 30 control Swiss white mice to 26% in the same number of treated animals.

Estuarine Pesticide Studies

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Abstract

During the past four years, the Bureau of Commercial Fisheries has been engaged in a nation-wide pesticide research program involving laboratory and field studies to determine the effects of pesticides on estuarine organisms. The acute toxicity of a majority of the more widely used chemicals has been established, under controlled laboratory conditions, to plankton, crabs, shrimp, oysters, and fish. The sub-lethal effects of some of the most important insecticides have been studied by exposing mollusks and fish to low concentrations for several months. The significance of laboratory data is being evaluated in the field by the study of pilot scale applications and large scale pest control programs.

The economic importance of pesticides insures that not only will they be widely used for some time to come but also that a variety of new types and formulations will be developed to fill specific needs. Consequently, a continuing objective of the research program must be the screening of these chemicals to evaluate their effect on commercial fisheries resources. At the same time it will be possible to assist manufacturing chemists in the screening of potentially

useful but still undeveloped compounds. This screening program requires the development of standard testing techniques which may be modified and augmented as our knowledge and needs increase.

The potential hazard of pesticide use has been clearly shown by laboratory observations but with few exceptions we are still unaware of the magnitude of their danger to our natural resources under field conditions. Therefore, a second objective of our expanding field program is the comparison of the acute and residual toxicities of these chemicals under a variety of field conditions with the relative toxic levels that were determined in laboratory tests.

Detailed studies are required to show how the persistence of chemicals in the environment may be affected by weather conditions, amount of ground cover, drainage patterns, and soil structure. Projects are also being designed to determine if some of the more important pesticides may be concentrated or biologically magnified in the estuarine food web. There is laboratory evidence that man's food supply may be contaminated even in areas where chemical contamination levels are extremely low.

Finally, it is proposed that teams of observers be trained to make appropriate before and after studies of large scale pest control programs to determine when and under what condition there may be significant danger to our natural resources. These teams will be concerned also with the monitoring of estuarine environments supporting important commercial fisheries. We are hopeful that technically and economically reasonable bio-assay methods will be developed so that we can maintain a continuing vigilance over the estuarine habitat.

Shellfish Advisory Service — Cooperation With the Industry

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MOLLUSK SHELLFISH at the present time account for more than 12 per cent of the total landed value of our domestic commercial fisheries. In cold cash this represents about 45 million dollars. They are therefore of major importance to our United States fisheries economy and of direct concern to us in the Bureau of Commercial Fisheries which, in cooperation with the research and management agencies of the maritime states, is charged with the conservation and wise management of these important natural resources. While all of us should be, and no doubt are, consumers of this fine food, we should be vitally aware also of the significant place members of the shellfish industry, with their background of experience, have in this discussion. This makes a quartet of forces, state and federal research, state and industry management, that must work together in complete harmony to stabilize and increase production, to improve quality, to stimulate consumer demand, and as a result to develop and maintain a healthy shellfish industry.

These statements imply that there are conditions under par in this industry. This is unfortunately so. The list of problems is long and I shall not enumerate them at this time. Dr. J. L. McHugh, Assistant Director for Biological Research of the U.S. Bureau of Commercial Fisheries, in his speech entitled "Research and the Oyster Industry" told the members of the Oyster Growers and Dealers

XI. United States Research Report, 1963

by H. W. Graham

The United States landed fish from Subareas 3, 4 and 5 in 1963 and conducted research in these three subareas as well.

Subarea 3

A. Status of the FisheriesI. Redfish

United States landings for Subarea 3 have been mostly from the Grand Bank, Div. 3N and 3O, with occasional trips from St. Pierre Bank, Div. 3P.

Landings in 1963 dropped about 15% over 1962, probably due to decreased effort since abundance in these areas has held steady during the past few years (Table 1).

Table 1. U.S. redfish statistics, Subarea 3 (metric tons, round weight)

<u>Year</u>	<u>Landings</u>	<u>Days fished</u>	<u>Catch per day</u>
1954	31,269	1,786	17.51
1955	13,406	1,126	11.91
1956	13,304	943	14.12
1957	4,797	289	16.62
1958	10,859	688	15.79
1959	16,871	1,120	15.07
1960	15,393	1,049	14.67
1961	16,706	1,056	15.83
1962	14,257	---	15.88
1963	12,098	---	---

B. Special Research StudiesI. Environmental Studies

1. Hydrographic. The U.S. Coast Guard, as the agency operating the International Ice Patrol, examined the temperature and salinity distribution from the surface to 1500 m in 4 network surveys of the Grand Banks region. The first survey, 30 March-8 April, covered the waters over and immediately seaward of the southern and eastern slopes of the Grand Banks from just westward of the Tail of the Banks northward to Section T, approximately 45-40 N. The

second survey, 15 April-25 April, covered the area immediately seaward of the eastern and northeastern slope of the Grand Banks from section T northwestward and included Flemish Cap and the Bonavista Triangle. The third and fourth surveys, 14 May-31 May, were combined into a single survey and covered an area similar to the first and second. The postseason survey, 13 July-21 July, occupied the Bonavista Triangle and the Labrador Sea section, (South Wolf Island, Labrador, to Cape Farewell. Greenland) to within 20 miles of shore at Cape Farewell.

The season was characterized by a less than normal amount of sea ice and icebergs along the east Newfoundland coast. Labrador Current volume along the eastern slope of the Grand Banks was slightly below normal for the entire season although well defined, was on the average warmer and saltier than normal, but with lower minimum observed temperatures. As the season progressed, conditions tended more toward the normal but still remained below normal. On the postseason survey, the Labrador Current off South Wolf Island had a positive volume anomaly and a negative temperature anomaly while the West Greenland Current off Cape Farewell had a negative volume anomaly and a positive temperature anomaly. The report in toto will be published in the U.S. Coast Guard Bulletin No. 49.

Subarea 4

A. Status of the Fisheries

I. Haddock

United States landings from Browns Bank and LaHave Bank were about the same in 1963 as in 1962 (Table 2). Total landings for the U.S. and Canada combined will probably also be about the same as in 1962. The abundance was about the same as last year, actually showing a slight drop. Total effort in 1963 will probably show an increase over the relatively low level of 1962.

Table 2. U.S. haddock statistics, Subarea 4 (metric tons, round fresh)

<u>Year</u>	<u>Landings</u>	<u>Days fished</u>	<u>Landings/day</u>
1956	14,024	1,215	11.540
1957	8,951	1,015	8.818
1958	12,639	1,374	9.199
1959	10,544	1,777	5.933
1960	8,466	1,169	7.239
1961	9,330	1,318	7.076
1962	6,440	739	8.709
1963	7,286	1,013	7.185

The age composition of landings for 1963 and previous years (Fig. 1) indicates an increased proportion of four and five-year-olds in 1962 and 1963. The 1963 fishery depended heavily on the 1958 and 1959 year-classes as did the Georges Bank fishery. However, because of the slower growth rate in Subarea these year-classes should sustain the fishery during 1964, and provide a level of abundance near that of 1963.

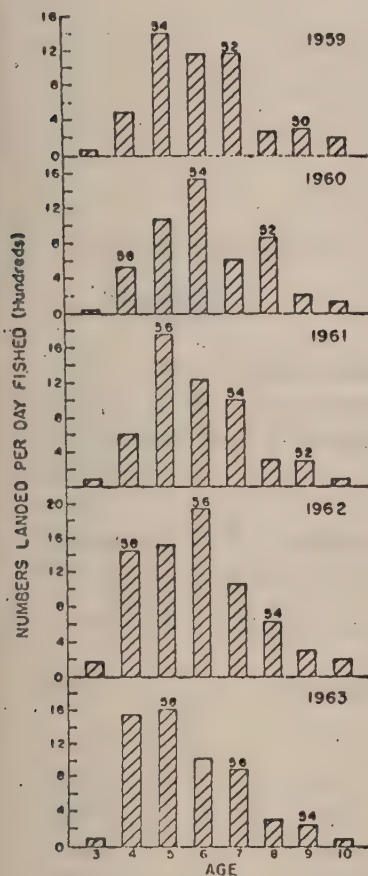


Fig. 1. Browns Bank haddock age composition.

A U.S.-Canada cooperative study of the Div. 4X haddock fishery for the period 1956-1961 was completed and a manuscript submitted for publication in the new ICNAF research journal. The study describes the general characteristics of the fishery and presents estimates of abundance, growth, year-class strength, and total mortality.

Average annual survival rate of Div. 4X stocks was approximately 0.50 corresponding to an instantaneous total mortality of 0.70. However, growth and age composition was not uniform in all parts of Div. 4X. Bay of Fundy haddock exhibit faster growth and a younger age composition than those from waters off southern Nova Scotia (including Browns Bank). Age composition of the Bay of Fundy haddock is similar to that of Div. 5Z (Georges Bank), but growth is still faster in the latter area. Both growth and age composition of haddock off southern Nova Scotia are similar to that for stocks off central Nova Scotia (Div. 4V-W).

Certain year-classes appeared strong in all Div. (5Z to 4W) suggesting that factors common to the entire area may often control brood success, or that some stocks mix at a pre-recruit stage.

II. Cod

United States landings of cod from the subarea were up slightly in 1963 but were near the 10-year average (Table 3).

Table 3. U.S. cod statistics, Subarea 4 (metric tons, round weight)

<u>Year</u>	<u>Landings</u>
1954	2,659
1955	1,371
1956	1,624
1957	1,083
1958	1,147
1959	862
1960	1,605
1961	1,261
1962	1,197
1963	1,347

III. Redfish

The steady decline in U.S. landings from the Gulf of St. Lawrence from a high of 34,739 metric tons in 1955 to 68 metric tons in 1962 was reversed in 1963 when 4,879 tons were landed. This was the result of increased effort (Table 4).

Table 4. U.S. redfish statistics, Subarea 4 R-S-T (Gulf of St. Lawrence) (metric tons, round weight)

<u>Year</u>	<u>Landings</u>	<u>Days fished</u>	<u>Catch per day</u>
1954	17,228	1,517	11.35
1955	34,739	2,397	14.49
1956	24,825	2,024	12.26
1957	18,319	1,960	9.34
1958	7,535	844	8.93
1959	5,406	572	9.45
1960	1,412	139	10.13
1961	200	20	9.84
1962	68	---	---
1963	4,879	---	---

The catch from Nova Scotian banks decreased about 20% in 1963 also due to change in effort. The abundance has been steady in this area for several years (Table 5.)

Table 5. U.S. redfish statistics, Subarea 4 V-W-X (Nova Scotia Banks) (metric tons, round weight)

<u>Year</u>	<u>Landings</u>	<u>Days fished</u>	<u>Catch per day</u>
1954	20,895	1,900	11.00
1955	9,330	1,100	8.48
1956	16,313	1,461	11.17
1957	21,101	1,896	11.13
1958	30,768	2,556	12.04
1959	25,281	2,448	10.33
1960	36,612	3,352	10.92
1961	28,957	3,000	9.65
1962	29,375	---	10.89
1963	23,282	---	---

B. Special Research Studies

I. Biological Studies

Serology of haddock. Preliminary results with a rabbit anti-haddock serum have revealed statistically significant serological differences between haddock from Cape Cod, Browns Bank, and Emerald Bank. However, the genetic significance of these differences has not yet been established. Haddock blood samples from Nova Scotian waters were obtained through the generous cooperation of Canadian scientists aboard the R/V A. T. Cameron.

Subarea 5

A. Status of the Fisheries

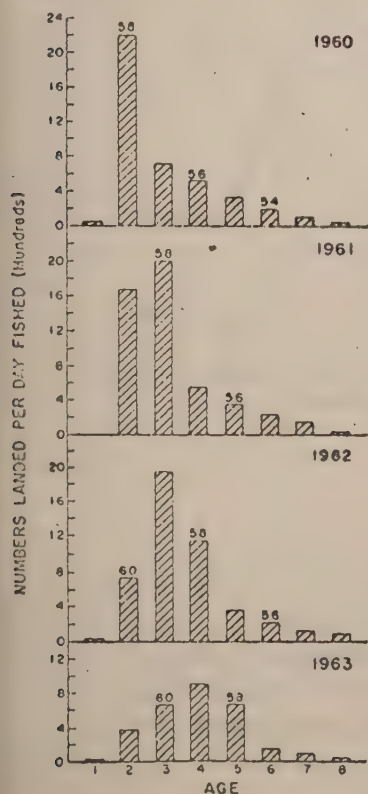
I. Haddock

The U.S. landings of haddock from Georges Bank dropped 5,000 metric tons in 1963 (Table 6). This was due to a decreased abundance of fish, the index of abundance dropping from 6.6 in 1962 to 4.6 metric tons per day in 1963.

Table 6. U.S. haddock statistics, Subarea 5 (metric tons in round weight)

Year	Total Subarea 5 Landings	Div. 5Z (Georges Bank)	
		Abundance index	Effort days fished
1954	53,539	8.382	5,807
1955	50,344	9.491	5,059
1956	59,422	7.566	6,794
1957	54,702	6.205	7,825
1958	44,404	4.790	7,836
1959	40,548	4.028	9,432
1960	45,341	5.661	7,669
1961	51,681	6.858	7,192
1962	54,412	6.641	7,833
1963	48,868	4.572	10,098

The 1958 and 1959 year-classes which have supported the fishery in the past few years are losing their dominance in the age structure of the populations while the following year-classes, 1960 to 1962, are weak ones (Fig. 2). Thus the abundance of haddock on Georges Bank is expected to remain relatively low during 1964.



On R/V Albatross IV groundfish survey cruises during the summer and fall of 1963 an unusual abundance of young-of-the-year haddock were found which indicates that the 1963 year-class is an unusually large one. On this basis we can expect an abundance of scrod to appear in the fishery early in 1965, and that landings would begin to improve during that year.

Refining abundance index. Relative abundance and total effort for haddock and cod in Subarea 5 have been estimated from a constant, small group of large Boston otter trawlers since about 1920. This index is not entirely satisfactory, and we have begun studies directed towards providing a more appropriate index based on a greater and more representative segment of the fleet. These studies will include a comparison of temporal and spatial variation in catch and

Fig. 2. Georges Bank haddock age composition.

effort of the several component fleets, and estimation of relative efficiency of various types of gear and vessel size. These studies involve data covering over 30 years of fishing; hence will require some time for completion.

Estimating pre-recruits. In recent years the United States has conducted fairly regular surveys each fall of the distribution and abundance of otter trawl-caught fish from the Bay of Fundy to the Hudson Canyon off New York. A preliminary analysis was completed of catches of young-of-the-year haddock to determine annual fluctuations free from potential errors due to effects of area, depth, and time of day. A log transformation markedly reduced but did not eliminate the correlation between mean and variance of catches. Nevertheless a preliminary analysis of variance (ignoring interaction terms involving factors of depth, area, and time of day) indicated significant between-year differences in mean catch rate. More important, there is a fairly good correspondence between young-of-the-year haddock abundance indices on Georges Bank, and the subsequent abundance of the same year-classes at ages 2 and 3 in the commercial landings (Fig. 3). This suggests not only the potential predictive value of the surveys, but also tends to confirm the long held view that factors determining year-class strength operate chiefly in the first few months of life.

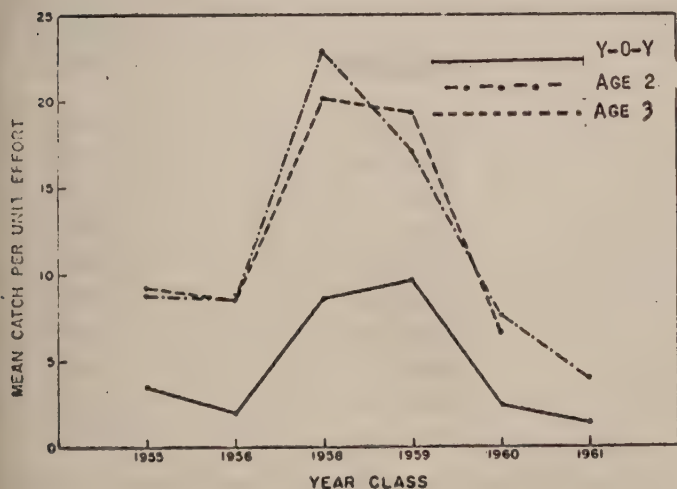
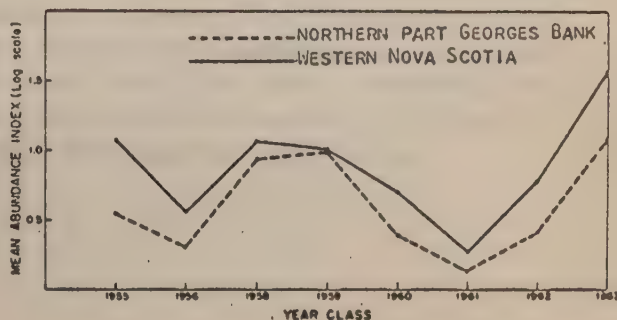


Fig. 3. Comparison of haddock year-class abundance indices on Georges Bank (Y-O-Y based on fall surveys, ages 2 and 3 based on annual catch per day in numbers in commercial landings

Fig. 4. Comparison of Y-O-Y haddock abundance indices of Western Nova Scotia and Northern part of Georges Bank.



Another interesting feature is the correspondence between young-of-the-year indices on Georges Bank and off western Nova Scotia. It appears that strong and weak broods tend to occur in the same years in both areas (Fig. 4). This is further evidence of the correspondence in brood success among New England and Nova Scotian haddock stocks, and lends additional support to the hypothesis that pre-recruit dispersion or environmental factors common to the entire area, may be involved. Finally, it may be noted that the brood index is consistently higher off western Nova Scotia than on Georges Bank. The significance of this feature is not yet known.

II. Cod

U.S. landings of cod dropped about 2,000 metric tons in 1963 after reaching a 10-year high of 18,000 metric tons in 1962 (Table 7). This change is probably related to abundance as the index also reached a 10-year high in 1962. Although we do not have age compositions it appears from length frequencies that the changes in abundance have been due to changes in year-class strength. Abundance is expected to remain high for a year or so.

Table 7. U.S. cod statistics, Subarea 5 (metric tons, round fresh)

<u>Year</u>	<u>Landings</u>	<u>Catch per day</u>	
		<u>Total cod</u>	<u>Scrod cod</u>
1954	12,237	1.143	0.125
1955	12,457	1.393	0.129
1956	13,238	1.477	0.113
1957	13,160	1.313	0.077
1958	16,252	1.072	0.297
1959	16,218	1.402	0.316
1960	14,282	1.407	0.284
1961	17,669	2.071	0.492
1962	18,626	2.268	0.465
1963	16,499	---	---

III. Silver hake

United States foodfish landings amounted to about 39,000 metric tons, a slight decrease from 1962. The preliminary estimate of abundance, 17.4 metric tons per day-fished is nearly the same as in 1962 (Table 8). However, the U.S. vessels fished more on inshore grounds in 1962 and again in 1963 and thus avoided the principal areas fished by the USSR on Georges Bank.

Table 8. U.S. silver hake statistics, Subarea 5 (metric tons, round weight)

Year	For Food	For Industrial	For Animal Food	Total	Catch per day
1954	40,823	9,525	2,722	53,070	---
1955	50,348	10,433	4,536	65,317	---
1956	40,370	13,608	4,989	58,967	---
1957	45,300	17,200	7,200	69,700	---
1958	48,500	10,400	7,700	66,600	---
1959	49,900	11,800	9,100	70,800	---
1960	46,700	2,300	9,100	58,100	17.5
1961	38,100	3,200	4,500	45,800	23.8
1962	37,200	3,200	7,200	47,600	18.5
1963	39,205	8,478	*	47,683	17.8

*Value not available

Examination of length-frequency compositions of port landings and catches aboard fishing vessels has indicated that in 1962 and 1963 fish under 25 cm were rather less abundant than in previous years. This is not reflected in the abundance index because the small sizes are not landed for food in the U.S. If these observations do, in fact, reflect on the population, the combination of weak recruitment and increased fishing effort may cause a decrease in abundance in the next few years.



Fig. 5. Length-frequency of Silver Hake, U.S. landings for food in 1963.

The majority of fish in the U.S. landings in 1963 is in the 25-40 cm length classes (Fig. 5). The results from ageing studies thus far conducted indicate that these fish are mostly 3 and 4 years old, and that only the largest 10% were over 5 years of age.

IV. Redfish

United States landings of redfish from the Gulf of Maine dropped significantly in 1963 in the face of increased abundance (Table 9). This was due to a decrease in effort. The length frequencies show that small fish are relatively more abundant than they usually are. The increased abundance coupled with the large proportion of small fish indicates that one or more strong year-classes are entering the fishery. On this assumption we can expect abundance to hold up for a few years.

Table 9. U.S. redfish statistics, Subarea 5 (Gulf of Maine) (metric tons, round weight)

Year	Landings	Days fished	Catch per day
1954	12,988	3,859	3.37
1955	13,914	3,089	4.50
1956	14,388	3,267	4.40
1957	16,468	3,862	4.26
1958	16,112	3,636	4.43
1959	14,435	3,329	4.34
1960	10,716	2,799	3.83
1961	14,040	3,077	4.56
1962	12,540	---	4.76
1963	8,871	---	---

Through 1960 it was not possible to discern any trend in the average size of redfish in the Gulf of Maine. With the addition of the 1961 and 1962 data there now appears to have been a long term reduction in average size of fish in both males and females. However, as pointed out above, the recent low average size may bode well for the fishery during the next few years (Fig. 6 and 7).

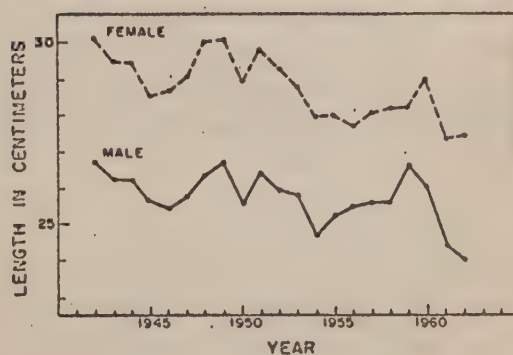
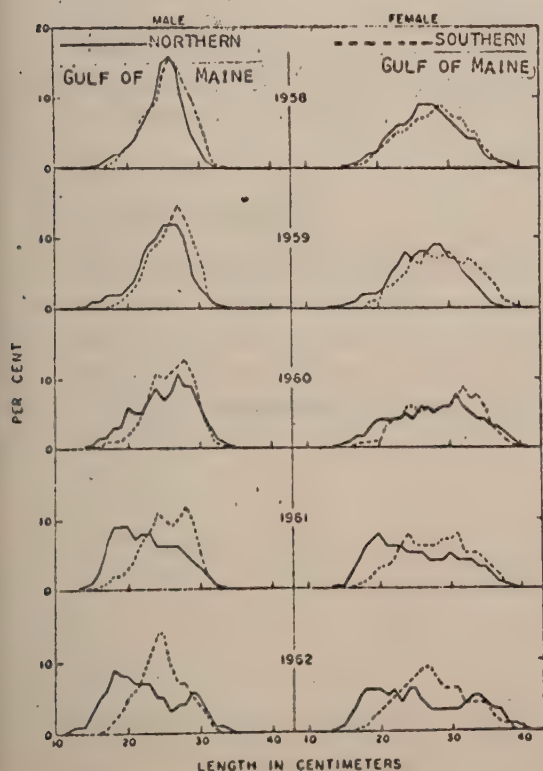


Fig. 7. Average length of landed redfish from the Gulf of Maine, 1942-1962.

Fig. 6. Redfish length frequencies, Gulf of Maine.

Yellowtail flounder (*Limanda ferruginea*)

United States landings of yellowtail flounder reached an all-time high of 20,000 tons in 1963 (Table 10). This was due to unusually high abundance caused by three strong consecutive year-classes, 1958, 1959, and 1960.

Table 10. U.S. yellowtail flounder statistics, Subarea 5 (metric tons in round weight)

Year	South. New England Grounds		Georges Bank		Cape Cod Grounds	
	Landings	Landings per day	Landings	Landings per day	Landings	Landings per day
1954	1,515	1.270	2,887	2.086	1,120	1.270
1955	2,180	1.406	2,946	2.404	1,304	1.315
1956	3,542	1.542	1,594	2.041	1,472	1.089
1957	5,441	2.313	2,302	2.812	2,357	1.633
1958	8,907	2.449	4,534	3.220	1,613	1.724
1959	7,738	1.587	4,130	2.086	1,526	1.996
1960	7,843	1.769	4,447	2.222	1,812	1.633
1961	11,632	2.495	4,248	2.359	1,880	2.041
1962	15,669	3.674	7,769	3.583	1,973	1.724
1963 ^{1/}	21,882	4.672	10,990	4.173	2,186	1.950
/ Preliminary						

During the coming year the 1959 and 1960 year-classes will continue to contribute heavily to the fishery, but the 1961 year-class appears to be a weak one. The overall abundance of marketable sizes will probably drop slightly during 1964.

I. Industrial Fishery

The industrial fishery catches fish primarily for purposes of reduction to meal and oil, and for purposes of supplying animal food products. The fishery began in the late 1940's, reached a peak in 1956 when 111,000 metric tons were landed. The fishery gradually declined to a level of 24,000 metric tons in 1960, but is beginning to increase again and 54,000 metric tons were landed in 1963 (Table 11).

Table 11. U.S. landings of industrial trawl fish from Subarea 5 (tons in round weight)

<u>Year</u>	<u>Landings</u>
1956	110,786
1957	97,736
1958	88,927
1959	75,706
1960	24,492
1961	32,132
1962	30,094
1963*	53,707
*Preliminary	

The fish are caught with small mesh nets, are generally not culled at sea as are the food-fish catches, and provide, therefore, more direct information on size and species composition of the area stocks. This is the only fishery which utilizes red hake, one of the species of major importance in the subarea's biomass.

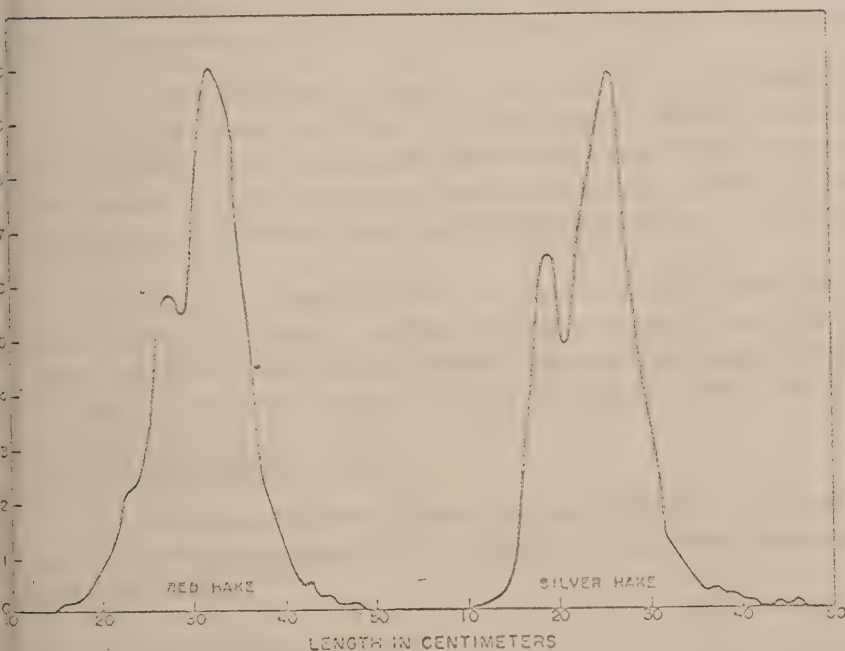


Fig. 8. Length frequencies of Silver and Red Hake in industrial catches from southern Subarea 5, 1963.

The landings are not reported by species, and a special sampling program is required to obtain estimates of species composition. The estimated species composition in 1963 (Table 12) indicates red hake and silver hake are the major components of the catch. These estimates apply to catches from the southern part of the subarea, where the fishery was concentrated. The length-frequency of these two main species is presented in Fig. 8.

Table 12. Species composition of industrial trawl fish caught in southern part of Subarea 5, 1963

Species	Percent	Metric Tons
Red hake.	44.7	19,511
Silver hake	29.6	12,920
Sea robins	6.0	2,619
Skates	6.0	2,619
Flounders	6.3	2,750
Other	7.4	3,230
Total	100.0	43,649

VII. Herring

The total Maine catch of herring for 1963 was 70,090 metric tons, a slight increase from the 1962 catch of 69,473 metric tons. In 1963 only 46,457 metric tons were processed as sardines and for reduction purposes as compared with 58,302 metric tons in 1962. This change reflects a condition of market inventories and is not related to changes in abundance or availability. The sardine canneries ceased operation in the early autumn of 1963, while the fish supply was still plentiful. The quantities of herring sold for lobster bait in 1963 increased 40% over 1962 and totalled 16,921 metric tons.

In the sardine fishery, the total units of gear decreased from 278 in 1962 to 224 units in 1963, a decrease of 20% as compared with a catch decrease of only 4%. This indicates that the availability of fish may have been greater in 1963 even though the case-pack was much lower. The decrease in gear units was apparent in the three major types: weirs, stop-seines and purse seines.

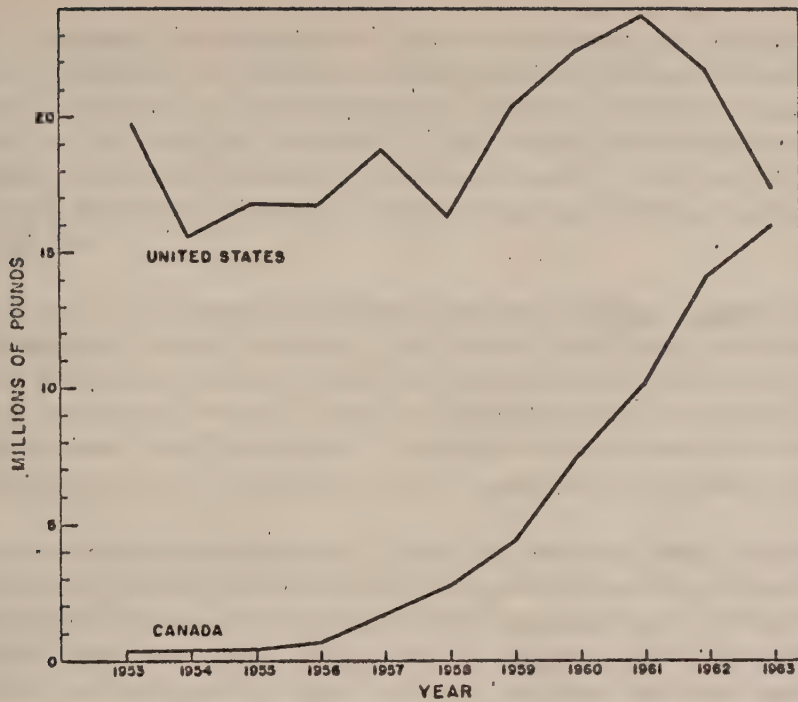
The age compositions of the herring taken by the sardine fishery were dominated, as usual, by fish in their second year of life. Three-year-olds contributed a relatively greater proportion than usual during June, July and August -- accounting for 10,000 of the 50,000 metric tons taken in that period.

VIII. Other pelagic fish

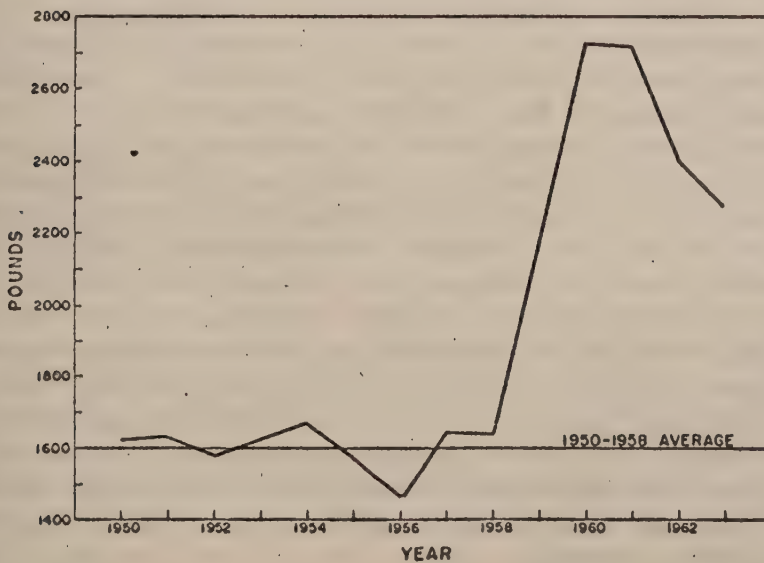
An Atlantic tuna purse seine fishery has started in the U.S. and, to obtain records pertinent to the catch, a log book system was introduced in the fleet in 1962.

IX. Sea scallops

United States landings of sea scallop meats from Div. 5Z have been declining since 1961 while Canadian landings have continued to rise (Fig. 9). Ten years ago, the Canadian fishery accounted for less than 1% of the landings while in 1963 it accounted for almost half of them. The large increase in total landings since 1958 has been a reflection of the expansion of the Canadian fleet coinciding with a real increase in abundance during the years 1959-61 (Fig. 10).



g. 9. Landings of sea scallop meats by the United States and Canada, 1953-1963.



g. 10. Relative abundance of sea scallops from Georges Bank (catch per day of U.S. fleet).

This increase was caused by the recruitment of a dominant year-class to the fishery in 1959. Although the phenomenon of occasional dominant year-classes is well-known in other fisheries, this is the first record of it having occurred in the sea scallop fishery. This single year-class has supplied a large fraction of the catch for the past few years. It is largely fished out now and there is no evidence to suggest that it has or will be replaced with an equally large one.

We can also estimate relative abundance from quantitative samples collected on research vessel cruises. In May of 1961 our data showed an average catch of 106.6 scallops over 70 mm in length per 10,000 square feet dredged. Returning to the same areas in May of 1962 we found concentrations of 97.6 per 10,000 square feet, an 8% decline. Similar cruises were carried out in September of both years. Comparing these samples we found a 40% decline.

These figures cannot be accepted as strictly valid measures of change in abundance with time since the cruises did not cover all of Georges Bank and the sampling density was something less than satisfactory. They do, however, indicate a trend downward and coupled with the drop in the landings per day fished during 1962-63 as compared with 1960-61 suggest that perhaps the level of abundance on Georges Bank is returning to that which prevailed during 1950-58.

B. Special Research Studies

Environmental Studies

1. Hydrographic. The BCF Biological Laboratory at Boothbay Harbor continued their environmental surveys in the nearshore waters from Cape Ann to Grand Manan. The surveys were designed to study prerecruit herring and involved measures of herring abundance and availability and environmental factors controlling their recruitment to the coastal sardine fishery. Hydrographic observations obtained concurrently with larval herring collections were concerned with detecting seasonal and areal changes in the environment. Temperature, salinity, transparency, density, and nontidal drift (drift bottles and sea-bed drifters) were monitored along the coast and inshore. Analyses of these observations suggest: (1) that the movement of larval herring into some estuaries and embayments along the coast is not dependent upon a nontidal two-layer current system, but rather a lateral system or merely inshore and upstream stranding of the larvae by tides, (2) that there are differences in the physical oceanic characteristics along the Gulf of Maine coast and these differences divide the eastern and western sectors of the coast, (3) that monitored inshore stations show appreciable differences in their salinity and density distributions from year to year dependent upon river discharge and runoff.

Bathythermograph traces were collected routinely by BCF research vessels Albatross IV and Delaware.

2. Benthic. United States benthic studies of the Gulf of Maine, Georges Bank, and southern New England waters were continued. More than 1000 samples were collected, 505 of which were analyzed during the year. The biomass in the Gulf of Maine is, on the average, about half of that on Georges Bank. South of Nantucket Island, where the biomass is generally comparable to that on Georges Bank, there appear to be five macrobenthic faunal communities.

II. Biological Studies

1. Cod. Analysis of tag returns showed that growth of cod is not inhibited with either the Petersen disc or Lea hydrostatic capsules with coelomic anchors.

2. Silver hake. Studies of methods of ageing silver hake were carried out in 1963 with the examination of otoliths collected in previous years. The otoliths had been stored in alcohol and lacked the clarity necessary for consistent detection of differential growth zones. We have, therefore, initiated the collection and analysis of fresh otoliths over a year's time to permit more consistent interpretation and validation of annual growth zones.

3. Redfish. Further studies of Eastport redfish corroborated earlier findings that different types of tags have quite different effects on the growth rate of the fish.

Analysis of the records of incidence of the parasite Sphyrion lumpi (Krøyer) collected continuously since 1942 was completed. Parasite increase during the period 1957-1962 was more than double the incidence during the period 1942-1947. There are indications that Sphyrion infestation is important in the natural mortality of redfish in the Gulf of Maine.

4. Yellowtail flounder. A study of the relation of abundance to fishing effort over the past 20 years for the three separate New England stocks was completed. It was concluded that the fluctuations in abundance which occurred were unrelated to fishing effort.

5. Winter flounder. About 10,000 winter flounder were tagged by the U.S. during March to May, 1964. The fish were tagged in both inshore and offshore waters as follows: (1) north of Cape Cod from Cape Ann to Cape Cod Bay, 3,000 fish; (2) south of Cape Cod in Nantucket and Vineyard Sounds and in Buzzards Bay, 3,000 fish; (3) off the eastern end of Cape Cod from Race Point to Chatham, 1,000 fish; (4) on Nantucket Shoals, 1,300 fish; and (5) on Georges Bank, 1,075 fish. The tags used were Bureau of Commercial Fisheries 1/2-inch Petersen discs fastened to the nape. This tagging endeavor was a joint project of the Massachusetts Division of Marine Fisheries and the U.S. Bureau of Commercial Fisheries, the Massachusetts Division tagging in inshore waters while the Bureau of Commercial Fisheries tagged on the offshore banks.

6. Herring. Samples of adult herring were collected whenever possible on a monthly basis from Georges Bank and the Gulf of Maine to compare spawning time, age-length data, meristic characters, and blood groups. Analysis of maturity stages indicated that spawning occurred principally from late September to early November. Some evidences of spawning was recorded during late July in the Gulf of Maine and late August on Georges Bank. December spawning in both areas was more evident in 1963 than in past years. There was no evidence of spring spawning on the Bank, while a few full and recently spent herring were taken in May and June in the Gulf of Maine. Spawning herring were principally 22 cm (standard length) at their first spawning, generally during the fourth year of life, though occasional three-year-old herring were found spawning on the Bank. Immature fish were found on occasion from January through October and their numbers increased in the November and December samples.

Age composition of samples from January through October from Georges Bank indicated that 1958 was the dominant year-class; followed in rank of percentage occurrence by the 1960, 1959, 1957, 1956 and 1955 year-classes. In November and December over 70% of the herring sampled were of the 1960 year-class. In the Gulf of Maine, the 1958 year-class was dominant in samples obtained from January through June; followed in rank of percentage occurrence by the 1960, 1957, 1959, 1956, and 1954 year-classes. From July through October, the 1959 year-class dominated the samples. In November and December, 1960 was the dominant year-class. In November representatives of the 1961 year-class were obtained.

Studies of the seasonal and areal changes in the distribution and abundance of herring larvae along the Gulf of Maine coast were continued during the past year. An abundance of yolk-sac herring larvae were obtained for the first time in an inshore area, documenting the existence of coastal spawning. Larval herring were "tracked" throughout the winter by utilizing newly developed high speed trawls and anchored nets. Results of this study have added to our knowledge of herring larval growth, distribution, and abundance in the inshore habitat. Analyses of previously collected data and the results of exploration during the past year demonstrate that herring larvae significantly utilize estuaries and embayments along the coast of the Gulf of Maine.

7. Other pelagic fish. R/V Delaware conducted exploratory fishing operations in the area during which 29 bluefin were tagged. Four fish have already been recovered by the purse seine fishery.

NORWEGIAN BLUEFIN TUNA SEINES

Faster Sinking, Faster Hauling than U.S. Nets

By ROGER E. GREEN¹

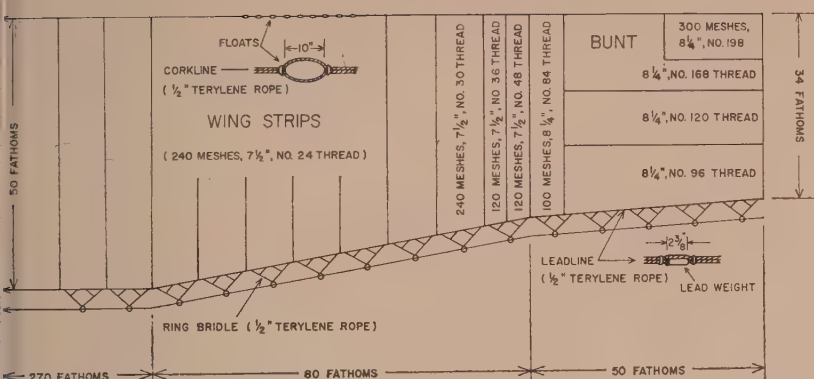


Figure 1—Construction details of a Norwegian purse seine used on Bluefin tuna (after Hamre, 1963).

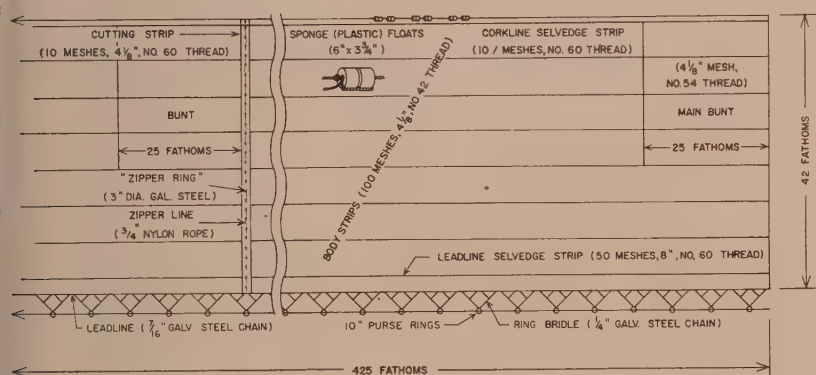


Figure 2—Construction details of a typical American tuna purse seine (after McNeely, 1961).

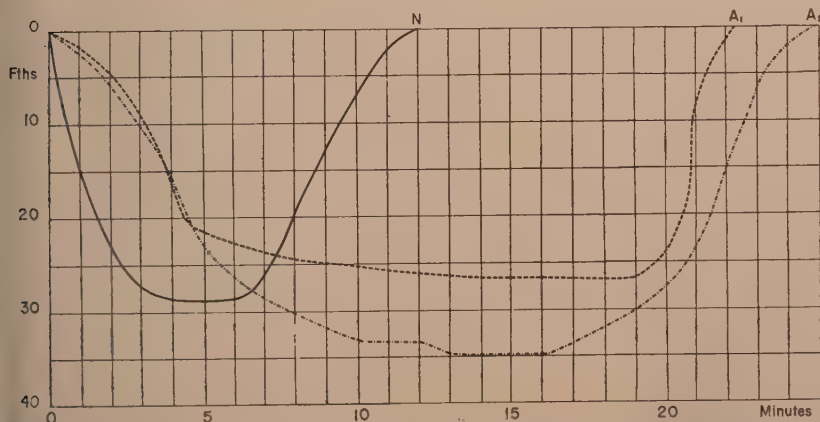


Figure 3—Comparison of sinking rates and pursing rates, and the depths reached by American (A-1 and A-2) and Norwegian (N) purse seines. Depth in fathoms on vertical scale and time in minutes on horizontal scale (after Hamre, 1963, and Hester, 1961).

● American tuna fishermen will be interested to note the development of purse seines in the Norwegian Bluefin tuna fishery as described in a recent article by Johannes Hamre² and to compare the seines in use in Norway with their own nets. The following comments are offered as a review of Hamre's article in order to acquaint American fishermen with the Norwegian tuna purse seine which is quite different from their own. The Norwegian seines have evolved for about 20 years and the form in use today, according to Hamre, is based mainly on the observation that the Bluefin try to avoid net walls irrespective of whether the meshes are small or large and the twine flimsy or heavy, at least within wide limits.

The most significant differences between the American and Norwegian nets (figures 1 and 2) are the extremely light construction of the wing of the latter and the much greater percent of hang-in. The light construction of the wing is possible since its only function is to encircle the tuna and lead them into the heavier bunt section as the wing is hauled in by power block and stacked. Due to the lightness of the wing, it is necessary to hold it open to prevent crowding the fish. This requires an extra boat, and the Norwegians use a "helper" boat of some 40 feet in length to tow the seiner off the net while the skiff, an 18-foot boat of 20 horsepower, tows the corkline in the opposite direction. If the set is successful, a second skiff on deck is put to sea to assist in keeping the net open.

● The construction of the wing and transition section is of vertical strips of webbing, in contrast to the American method of horizontal strips. Using vertical strips makes modification of the net's length easier. The nets are frequently enlarged by adding strips of webbing. Individual net sizes vary considerably around the average size diagrammed in figure 1 (Hamre, 1963). The vertical strips are laced together and to cork- and leadline selvage strips. The webbing is hung-in about 60 percent to the corkline (10 fathoms of stretched webbing is hung to 4 fathoms of corkline) and some percent less to the leadline. American nets are usually hung-in 10 percent to the cork-

line and 11 percent to the headline.³

In the Norwegian nets, doubled terylene ropes of about $\frac{1}{2}$ " in diameter each are used in the corkline and also in the headline, instead of steel chain as in American nets. The Norwegian purse-ring bridles also are made of this rope. The purse line is about $\frac{3}{8}$ " stainless steel cable. The headline weight, including purse rings, of the Norwegian net is, therefore, considerably lighter, averaging about $6\frac{1}{2}$ pounds per fathom, which is about one-fifth the weight on American nets. According to Hamre, much less power is required to purse the Norwegian net.

In spite of the light headline, the Norwegian net sinks 3 to 4 times as fast as the American net in the first 3 minutes after setting, and may be pursed in about half the time required for the American net, according to tests conducted by Hamre (1963) and Hester (1961).⁴ Both of these tests were conducted with the bathykymograph, developed by Hester, which was attached to the headline near half-net. This instrument gives a continuous tracing of depth with time, starting from the time the instrument enters the water and ending with the completion of pursing. Results of the comparison are shown in figure 3 (Hamre,

1963) where N is the tracing of the Norwegian net, and A¹ and A² are traces of the American net under two different conditions of wind and current. A¹ represents a set when wind and current were tending to drive the boat and the net apart, and A² when the boat drifted into the net, allowing the headline to sink deeper. The larger mesh size, lighter twine, and higher percent of hang-in are apparently responsible for the faster action of the Norwegian net in the water. Hamre thinks that, on a theoretical basis, the Norwegian net may be hung too loosely and the American net may be not loose enough.

● According to Hamre, the difficulties encountered by the Norwegians in the development of a suitable purse seine were to construct a net which would hold the fish and, at the same time, be manageable. The average seiner is about 70 feet in length. The fishery is conducted on very large Bluefin ranging in weight from 66 to 880 pounds, and averaging between 100 to 300 pounds. It took 20 years to work out the problem of combining necessary strength with sufficient net size. The annual Norwegian Bluefin catch was about 100 tons before

seines were used successfully in the late 1940's. During the past decade, it has varied from 3,000 to 14,000 tons.

Hamre (personal communication) states that the average catch is 3 to 6 tons per successful set. No information is available on the percent of sets with this net which are successful or catch-per-days-fishing which could be used to judge the relative efficiency of the Norwegian seine with its American counterpart. Disadvantages of the Norwegian net are the low breaking strength of the webbing in the wing, which may allow penetration by sharks and other animals, and its lack of cutting strips in the bunt section to allow separation of large catches into batches. However, according to Hamre, Bluefin schools as large as 91 tons have been caught in Norwegian waters with this type of net.

¹ Bureau of Commercial Fisheries Biological Laboratory, San Diego, California.

² Hamre, Johannes. 1963. Some Technological Aspects of the Norwegian Tuna Purse Seine Fishery. *Reports on Norwegian Fishery and Marine Investigations*, 13(6): 106-119.

³ McNeely, R. L. Purse Seine Revolution in Tuna Fishing. *Pacific Fisherman*. June 1961: 27-58.

⁴ Hester, F. J. Tuna Seines: How Deep? *Pacific Fisherman*. November 1961: 19-20.

Reprinted from PACIFIC FISHERMAN, January 1964

A RANGE EXTENSION OF THE RARE ARGENTINOID FISH, *XENOPHTHALMICHTHYS DANAE* (MICROSTOMIDAE).—Only 3 specimens of *Xenophtalmichthys danae* Regan have been reported from the Atlantic Ocean previously. Regan (1925, *Ann. Mag. Nat. Hist. Ser. 9*, 15:59–60) described the type, 88 mm standard length, obtained from near St. Lucia, in the Caribbean Sea, by the DANA Expedition 1921–1922 at DANA Station 1183 (Substation 14) (14° N lat, 61°40' W long; 2,500 m of wire out). Bertelsen (1958, *Dana Report* 45:3) noted 2 additional specimens from material collected in the eastern Atlantic Ocean by the DANA Expedition 1928–1930; 1 specimen, 59 mm standard length, taken off Freetown, Sierra Leone, at DANA Station 4003 (8°26' N lat, 15°11' W long; 1,000 m of wire out); and 1 postlarval specimen, 16.5 mm standard length, taken just south of the equator off Liberia at DANA Station 4000 (0°31' S lat, 11°02' W long; 1,000 m of wire out).

A fourth specimen was taken in the western North Atlantic Ocean off northern Florida, by the U. S. Bureau of Commercial Fisheries exploratory fishing vessel SILVER BAY at Station 3726 (29°42' N lat, 80°10' W long; 185–190 fathoms; 70-ft flat trawl; 3 February 1962), and is deposited in the U. S. National Museum, USNM 188451.

Selected measurements and counts of the 4 Atlantic specimens are shown in Table 1, following Bertelsen. There is general agreement in the body proportions of the type, the 59-mm specimen, and the new specimen, except for measurements pertaining to the eye and the anal to caudal distance; the fin ray counts of all 4 specimens are in general agreement.

The capture of the SILVER BAY specimen represents an extension of the range of this species approximately 940 miles north and 1,100 miles west.

Rass (1961, *Zool. Zhur.* 40(12):1858–1861) described a new genus and species of Microstomidae, *Prososcopa stilbia*, from the Indian Ocean. This genus and species was subsequently placed in the synonymy of *Xenophtalmichthys danae* Regan by Rass (1962, *Zool. Zhur.* 41(10):1578–1579). Rass also noted an additional specimen of this species from the tropical Pacific, but no specific location given.—ELMER J. GUTHERZ, U. S. Bureau of Commercial Fisheries, Bio-

logical Laboratory, Brunswick, Georgia. Contribution No. 68 from U. S. Bureau of Commercial Fisheries Biological Laboratory, Brunswick, Georgia.

TABLE 1. SELECTED MEASUREMENTS AND MERISTIC DATA OF THE FOUR KNOWN ATLANTIC SPECIMENS OF *Xenophtalmichthys danae*

	DANA ¹ Station 4000	DANA ¹ Station 4003	Type DANA ¹ Station 1183 (Substa. 14)	SILVER BAY Station 3726
Standard length (mm)	16.5	59.0	88.0	91.0
Percentage of standard length:				
Depth (between head and ventral fins)	11.5	6.0	7.0	6.9
Head length (snout to margin of operculum)	17.5	15.5	14.6	14.2
Snout length (to anterior margin of eye)	2.3	1.7	1.2	1.3
Eye (longitudinal diameter)	6.5	7.0	6.0	7.4
Least interorbital width	2.8	1.5	1.1	0.9
Snout to ventral fin	50.0	44.0	40.0	40.2
Snout to dorsal fin	62.0	54.0	52.0	50.6
Snout to anal fin	77.0	72.0	70.0	70.9
Ventral fin to anal fin	27.0	28.0	30.0	32.1
Anal fin to caudal fin	23.0	28.0	30.0	26.7
Least depth of peduncle	4.5	2.7	2.9	2.7
Longest pectoral fin ray length	10.0	13.6	11.0	10.8
Percentage of head length:				
Snout length	17.0	11.0	9.0	9.2
Eye diameter	37.0	46.0	42.0	52.3
Lens diameter	13.0	19.0	20.0	27.6
Interorbital width	16.0	10.0	8.0	7.7
Dorsal fin rays	10	10	11	10
Anal fin rays	9	10	10	9
Pectoral fin rays	7	7	7	7
Ventral fin rays	8–9	9	9	9
Vertebrae				48
Branchiostegals				3

¹Bertelsen (1958, *Dana Report* 45:3).

STUDIES OF ALASKA RED SALMON. Edited by Ted S. Koo. University of Washington Press, Seattle, 1962, 449 pp., figures and photographs. \$8.50.

This is a volume of collected research reports originally submitted as graduate theses by the editor and other senior members of the Fisheries Research Institute, University of Washington. For those not immediately concerned with salmon research, the title of the reports will lie largely in the descriptions of approaches to salmon research problems and the methodology developed.

The editor contributes three papers to the volume: (1) "Age designation in salmon," a discussion of various methods used to designate the periods of freshwater and marine life of the Atlantic and Pacific salmon; (2) "Age and growth studies of salmon scales by graphical means," a description of scale growth in relation to the freshwater and marine life of salmon and the development of methods to reduce individual bias in the interpretation of salmon scales; and (3) "Differential scale characters among species of Pacific salmon," a brief description describing the distinctive characteristics of scales from the five species of Pacific salmon found in North America.

Dr. A. Mathisen contributes two unrelated papers: (1) "The effect of altered sex ratios on the spawning of red salmon," and (2) "Photographic enumeration of red salmon escapement." The first describes spawning experiments in which the ratio of males to females was varied. Under the conditions of the experiments, efficient fertilization occurred at ratios disproportionate as one male to fifteen females. The second paper describes a photographic method of counting red salmon as they migrate past a fixed point in a river.

Two reports by Robert L. Brugner are: (1) "Studies of red salmon smolts from the Wood River Lakes, Alaska," which describes studies related to measuring the abundance, growth, and survival of red salmon smolts in one of the Bristol Bay River systems, and to determining the causes of fluctuations, and (2) "Sampling red salmon fry by lake trap in the Wood River Lakes, Alaska," a description of sampling gear and methods.

Donald E. Bevan contributes, "Estimation by tagging of the size of migrating salmon populations in coastal waters." This is a report on tagging experiments in the coastal waters of Kodiak Island to

determine migration patterns of salmon runs and to measure the size of the populations.

In an introductory section, William F. Thompson, founder and for several years Director of the Fisheries Research Institute, following a long and illustrious career as Director of the School of Fisheries, University of Washington, describes the founding of the Institute and the philosophy underlying his direction of salmon research programs.

As a rule research theses find their way to archives where they are available to only a limited number of students. This volume was published with funds furnished by the Alaska Salmon Industry, the organization which sponsored and financed the Fisheries Research Institute during its early years and has continued to support some of the Institute's research programs.

M. G. HANAVAN

Bureau of Commercial Fisheries
Washington, D. C.

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64-71

The Shrimp Fishery of Alaska

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Abstract

Until 1958 the shrimp fishery of Alaska was confined to southeastern Alaska where from 1 to 2 million pounds of hand-picked shrimp were packed annually or more than 30 years. In 1958 the shrimp fishery expanded westward, with new plants in Seldovia, Kodiak, and Seward. Alaska has the potential for a much larger shrimp fishery than exists at present. Four species of shrimp are of commercial importance: *Pandalus borealis*, *P. platyceros*, *P. hypsinotus*, and *Pandalopsis dispar*, with pink shrimp (*P. borealis*) being of greatest importance.

Shrimp fishing by foreign powers in waters off Alaska has been primarily in the Bering Sea. The initial Japanese effort in 1961 took about 19 million pounds of shrimp, and in 1962, 40 million pounds were taken. In 1963 the U. S. Bureau of Commercial Fisheries received reliable reports of Soviet shrimp fishing in the Bering Sea.

A cooperative research program with the Alaska Department of Fish and Game is under way to study the biology and ecology of Alaska shrimp.

Processing problems of Alaska shrimp include loss of color, loss of natural fluids, and changes in flavor and texture. The Bureau of Commercial Fisheries Technological Laboratory at Ketchikan has started an active technological program relating to Alaska shrimp.

HISTORICAL REVIEW

THE SHRIMP FISHERY of Alaska was permanently established in 1916 at Petersburg by E. N. Ohmer and Karl I. Sifferman under the name of Alaskan Glacier Sea Food Company (Hynes, 1929). This firm is still actively processing Alaska shrimp and is now directed by David Ohmer, son of one of the founders. In 1916, production of shrimp meat began a gradual increase in southeastern Alaska which leveled off to about 500,000 pounds annually between 1924 and 1927. The industry remained almost exclusively in southeastern Alaska until 1958, and from 1 to 2 million pounds of shrimp (heads) were packed annually. The principal species processed was pink shrimp (*Pandalus borealis*). The meats were picked by hand and then shipped to market refrigerated or, in later years, frozen. Production was limited primarily by the cost of the hand labor involved in processing this small species. Approximately 6 pounds of cooked meats are obtained from 100 pounds of raw whole shrimp, which average about 100 shrimp to the pound.

With the installation of automatic picking machines, landings of whole shrimp in southeastern Alaska rose sharply from 2.4 million pounds in 1951 to 7.6 million pounds in 1958 (Table 1). Landings to the westward in the Gulf of Alaska area increased even more dramatically—from 30,000 pounds

TABLE 1
ALASKA SHRIMP LANDINGS, 1951-62 (IN THOUSANDS OF POUNDS, HEADS OFF)

Year	Area		Total
	Southeastern Alaska	Gulf of Alaska	
1951	1,707	1	1,708
1952	1,944	9	1,953
1953	1,722	12	1,734
1954	1,438	14	1,452
1955	1,777	51	1,828
1956	3,032	12	3,044
1957	2,350	30	2,380
1958	7,606	256	7,862
1959	5,519	7,534	13,053
1960	3,343	4,093	7,436
1961	4,212	11,768	15,980
1962	3,884	13,059	16,943

in 1957 to 7.5 million pounds in 1959, primarily at the ports of Seldovia, Kodiak, and Seward. Total Alaska landings increased from 7.9 million pounds in 1958 to 16.9 million pounds in 1962.

For comparison, 1962 production from other Pacific coast states of *Pandalus jordani*, a species similar to the Alaskan *borealis*, was as follows: Washington, 1.4 million pounds; Oregon, 2.0 million pounds; California, 1.8 million pounds. Alaska's production of 16.9 million pounds during this year placed it far in the lead as the principal producer of shrimp among the Pacific coast states.

COMMERCIAL SPECIES

The Alaska species of commercial shrimp are members of the family Pandalidae, which has a generally northern distribution, extending along the Pacific coast from California to the Bering Sea. *Pandalus borealis* is by far the most important species with *Pandalopsis dispar* (sidestripe shrimp) second in importance. *Pandalus goniurus* (humpy) and *P. hypsinotus* (coonstripe) are taken in small quantities in trawls, and a fifth species, *Pandalus platyceros* (spot), which is as large as the Gulf of Mexico penaeid shrimp, may readily be caught in pots fished in rocky areas 50 to 60 fathoms deep. Occasionally small pot fisheries supply local markets with this species.

SOUTHEASTERN ALASKA FISHERY

Since its beginning the shrimp fishery of southeastern Alaska has centered in the inside waters near Wrangell and Petersburg. The gear has been exclusively beam trawl, which differs from an otter trawl or Gulf shrimp trawl in that the mouth of the net is held open by a wooden timber rather than being spread by otter boards.

During the summer of 1962, the principal shrimp packing in southeastern Alaska was at Wrangell. Vessels fishing in this area were from 37 to 56 feet

g, and the beam holding the net open was 32 to 52 feet long. Usually day trips were made, the vessel leaving early in the morning and returning in the evening. In general, vessels fishing for a hand-picking operation made small catches, seldom exceeding 5,000 pounds a day; while those fishing for machine-picking operations occasionally brought in 10,000 pounds a day. Three picking machines were in operation in Wrangell in 1962, and in addition, there was a substantial production of hand-picked shrimp. The hand-picked shrimp were cold packed into 1- and 5-pound cans and quick frozen. The machine-picked shrimp were partially cooked, packed into 16-ounce cans, and pressure cooked.

GULF OF ALASKA FISHERY

In 1963 three shrimp plants operated in ports on the Gulf of Alaska: Kodiak, Kodiak, and Seward. Most of the shrimp delivered at these ports were taken with otter trawls just southeast of Kodiak Island. The trawl nets have an average width at the mouth of 70 feet, and the mesh in the cod end is from 1¼ to 1½ inches (stretched measure). The trawl is usually fished for about 2 hours and yields up to 12,000 pounds of shrimp. A trip usually lasts 3 days. A total landing of pink shrimp typically weighs about 60,000 pounds, while total landings of humpy and sidestripe shrimp are usually smaller. Most of the shrimp taken in the Gulf of Alaska are processed through an automatic picking machine after which they are usually frozen in blocks or canned.

POTENTIAL SHRIMP FISHING AREAS

The shrimp fishing grounds now under exploitation are only a small proportion of the area in Alaska with commercial potential. Exploratory fishing cruises by the U.S. Bureau of Commercial Fisheries give some idea of the potential for this fishery (Fig. 1). In southeastern Alaska, five cruises were

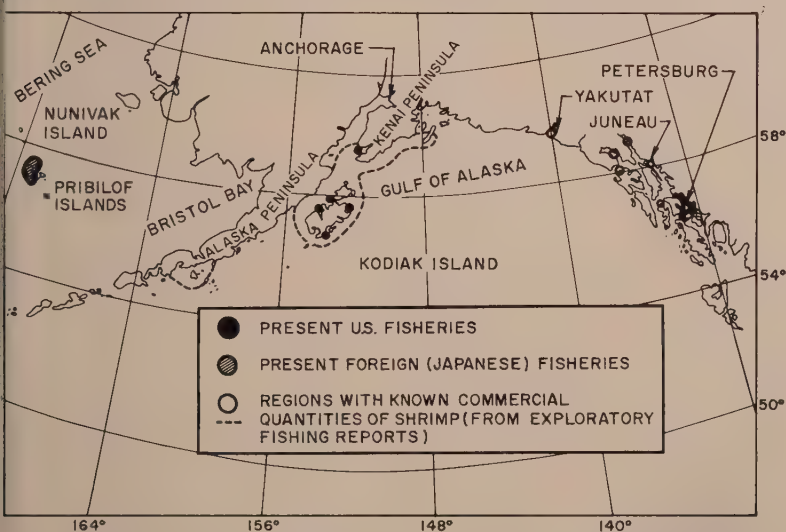


Fig. 1. Actual and potential shrimp fishing areas in Alaska.

made from 1950 to 1962 to assess shrimp abundance from Dixon Entrance to Cape Spencer (Ellson and Livingstone, 1952; Greenwood, 1958; Schaefers, 1951 and 1953). Commercial quantities of pink shrimp were taken in Idaho Inlet, Stephens Passage, Lynn Canal, Keku Strait, and Glacier Bay.

Exploratory shrimp operations have also been undertaken in the Gulf of Alaska, five cruises being made from 1953 to 1959 between Cape Spencer and western Kodiak Island (Greenwood, 1959; Schaefers and Smith, 1951; Schaefers, Smith, and Greenwood, 1955; Wathne and Johnson, 1961). Pink shrimp again was the dominant species, and excellent catches were made in lower Cook Inlet and Marmot Bay north of Kodiak Island, as well as in other bays around Kodiak Island. Inside waters of Prince William Sound have not produced large catches of pink shrimp, but this species is quite abundant in Yakutat Bay.

From August to October, 1962, exploratory fishing was conducted near the Kenai Peninsula and Prince William Sound with a semiballoon shrimp trawl measuring 70 feet along the footrope (U.S. Bureau of Commercial Fisheries, 1962). The dominant species was pink shrimp, and the best fishing was east of Montague Island where about 8,000 pounds of shrimp were taken in four 1-hour periods of fishing.

A 9-week cruise to determine shrimp potential between Prince William Sound and Chirikof Island, south of Kodiak Island, was taken in the summer of 1963 (U.S. Bureau of Commercial Fisheries, 1963). A 40-foot flat shrimp trawl was fished an average period of 30 minutes. In the area near Twoheaded Island immediately southeast of Kodiak Island, 64 fishing periods produced an average catch of more than 350 pounds and maximum catches of more than 3,000 pounds. The lower Cook Inlet-northern Shelikof Strait area also produced good catches of shrimp, with an average of about 220 pounds per half-hour period. Consistently high catches of sidestripe shrimp were made in northern Shelikof Strait. The catches in the area between Prince William Sound and the Kenai Peninsula were poor, less than 25 pounds per half-hour fishing period.

Only one exploratory cruise has been made off the Alaska Peninsula. This was made in 1957 in waters adjacent to the Shumagin Islands and from Stepovak Bay to Unalaska (Johnson, 1959). Catches of up to 3,500 pounds in 30 minutes of fishing were made in Pavlof Bay, and commercial quantities were taken in Beaver Bay, Balboa Bay near Sea Lion Rocks, and Stepovak Bay.

Present knowledge suggests that Alaska shrimp may be most abundant in waters adjacent to the Alaska Peninsula and perhaps along the Aleutian Islands and in the Bering Sea. None of these areas are now being fished by United States vessels. The shrimp potential is without doubt many times greater than present commercial production.

FISHING BY FOREIGN NATIONS

Japan began fishing off Alaska in 1933 in the eastern Bering Sea, and through 1937 two fishmeal factory ships operated in this area. There were no further fishing operations in the eastern Bering Sea until 1958 when 20 trawlers and a factory ship utilized groundfish stocks. The initial shrimping operation was in 1961 when Japan took about 19 million pounds of shrimp with catcher boats and one factory ship. In 1962 the approximate composition of the Japanese Bering Sea fleet was as follows: 4 fishmeal factory ships, 4 king crab factory ships, 3 longline factory ships, 2 factory stern trawlers,

whale factory ships, 23 support vessels, and 3 shrimp factory ships with 8 trawlers. Almost 40 million pounds of whole shrimp, mostly pink, were taken by the Japanese fleet in 1962. In 1963 two shrimp factory ships with 16 trawlers took about 46 million pounds of shrimp by early July in an area north of the Pribilof Islands.

Also in 1963, Japan sent four trawlers into the area south of the Alaska Peninsula and the Aleutian Islands to determine the abundance of fish and hellfish. An observer from the Bureau of Commercial Fisheries aboard one of these trawlers stated that about 5 or 6 tons of shrimp, mostly pink and ridestripe, were taken each day by a single trawler, and that this was the capacity of the freezing system. This exploratory operation may precede a much larger shrimp fishing effort in 1964 south of the Aleutian Islands and the Alaska Peninsula.

Shrimp are delivered to Japanese factory ships in the Bering Sea by catcher vessels during the day and are processed immediately or held in brine tanks on deck for night processing. Each factory ship has from two to four American-built picking machines. In 1962 the production of a single factory ship was estimated at 300,000 cases (twenty-four 7-ounce cans per case), with some additional amounts frozen in blocks. The United States is Japan's best customer and in 1962 imported about 169,000 cases of shrimp. Japan hopes to export 440,000 cases to the United States in 1963.

The status of the U.S.S.R. shrimp fishery in the Gulf of Alaska and the Bering Sea is not clear at present. The Soviets undertook exploratory shrimping operations in the western Gulf of Alaska in 1961 and made good catches in the vicinity of Sanak and Shumagin Islands. In March, 1963, an unconfirmed report indicated that six Soviet stern ramp trawlers were taking shrimp northwest of the Pribilof Islands.

There are no prospects for immediate exploitation of the Bering Sea shrimp stocks by United States fishermen. The Japanese fishery in this area will continue to produce shrimp in competition with the United States, and quite possibly the exploratory operation in the Gulf of Alaska will expand into another major Japanese fishery.

BIOLOGICAL STUDIES

The Bureau of Commercial Fisheries initiated a biological research program for shrimp in 1962, and in 1963 this was expanded into a cooperative study with the Alaska Department of Fish and Game. Samples of the commercial catch from southeastern Alaska and the Kodiak area are being taken to determine species, size and sex composition, and the egg-bearing period. Information on the life history of the various shrimp species is being obtained by towing plankton nets to collect the larval stages and fishing with pots and small otter trawls for the adults. Experimentation is under way to develop methods of marking shrimp following the general procedures biologists have developed in the Gulf of Mexico area.

Length composition of the adult pink shrimp indicates that there are four size classes, each of which appears to be an age class. The two age classes of smaller shrimp are males, and then a sex transition takes place, and the larger shrimp are females. The female carries her eggs on the ventral surface of her abdomen until they hatch. Egg-bearing females of the commercial species appear in the catch in the last half of September, and practically all females are egg bearing in January. The eggs hatch in March and April, and

larvae are present in the plankton samples through July. Only a bare beginning has been made in an understanding of the life history and population dynamics of Alaska shrimp.

PROCESSING PROBLEMS

The hand-picked and frozen shrimp from southeastern Alaska make an excellent product with a good market demand. The machine-picking operation however, is faced with some technological problems. Individual landings of shrimp to be processed by the picking machines are usually much larger than for the hand-picking operation. These large catches have resulted in some problems of proper holding aboard the vessels and storage in plants before processing. For efficient picking, processors have found it necessary to "age" shrimp before picking, and the consequent autolytic changes contribute to loss of color and natural fluids, as well as changes in flavor and texture. The Bureau of Commercial Fisheries Technological Laboratory in Ketchikan is beginning a program of research on these problems. Studies have been completed on holding shrimp in refrigerated sea water before processing, and new studies have started on the characteristics and stability of carotenoid pigments in Alaska shellfish. Other research is planned on the characteristics of the soluble protein and nonprotein nitrogen substances to learn more about the changes in the nitrogen compounds of shrimp that take place during sorting, processing, and storing. These compounds are intimately involved in texture changes and water binding capacity of shrimp handled in large quantities.

CONCLUSION

The Alaskan shrimp fishery has expanded rapidly and has a potential for a much greater expansion. The future of this industry is dependent on development of products with consumer demand that can be produced at a competitive price with similar products from other areas in the United States and from foreign countries.

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Tributary Homing of Sockeye Salmon at Brooks and Karluk Lakes, Alaska¹

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ABSTRACT

The degree of preference of sockeye salmon (*Oncorhynchus nerka*) for spawning in specific tributaries to Brooks and Karluk Lakes, Alaska, was studied in 1960 and 1961. Adult sockeye salmon begin to congregate around stream mouths soon after entering these lakes. At Brooks Lake, groups of fish were seined from various stream mouths and marked with distinctive tag color combinations. One group of tagged fish from each seine haul was released back into the original donor congregation as a control, and one or more groups were transported and released into congregations around other tributary mouths. Strength of tributary preference was determined by comparing the number of fish from each group distributed on the various spawning grounds. Eighty-three per cent of the 958 fish tagged were recovered at weirs and on stream and lake surveys. Distribution to spawning areas of sockeye salmon in control and transported groups was virtually identical. The study at Brooks Lake was followed by a study at Karluk Lake to explore further the strength of tributary preference. Very few sockeye salmon experimentally prevented from entering their preferred tributary chose an alternative spawning area. Most continued to attempt to enter their blocked tributary until death. A final study at Karluk Lake confirmed the fact that sockeye salmon entering the lake were predisposed to spawn in a particular tributary and could not be conditioned to enter an alternative tributary. We conclude that sockeye salmon are indeed homing to particular tributaries in these small lakes. The biological and management implications of these findings are discussed.

INTRODUCTION

SALMON LITERATURE strongly suggests that salmon home to large rivers and lake systems. Many of our present management techniques are based on this premise. This premise was seriously challenged many years ago by Huntsman (1937) and defended in rebuttal by many fishery scientists in three articles in a Pacific Coast fisheries trade magazine in 1937 (Anon., 1937a, b; Foerster, 1937). Recently, further evidence that discrete stocks of salmonids home to specific spawning areas within a major system has been obtained. Lindsey *et al.* (1959) clipped fins on young rainbow trout entering Loon Lake, B.C., from inlet and outlet spawning streams. About 94% of the trout returning as spawners homed to their parent streams. Stuart (1957) marked 2303 brown trout from spawning runs into six streams entering Dunalastair Reservoir, Scotland, over a 3-year period, 1952-54. Only 1 fish of the 709 recaptures in subsequent spawning runs did not return to its home stream; actually, this fish had homed successfully in 1953 and 1954 before being captured in another stream in 1955. Ricker (MS, 1959) suggests that salmon home not only to major river and lake systems but

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even to tributaries. Barnaby (1943) stated his opinion that "Under natural conditions, an extremely high percentage of the fish [salmon] returning to spawn proceed to the same area where they emerged from the spawning gravel as fry." Even as early as 1918, Gilbert (1919, 1920) began recognizing certain local sockeye salmon spawning groups in the Fraser River system, for instance, the Harrison Rapids group which is characterized by lack of any significant freshwater residency as young before they migrate to salt water. Schaefer (1951) stated that "The various groups of sockeye in the Harrison River system form one of the classic examples of racial differentiation of salmonid fishes."

Two types of evidence at Brooks and Karluk Lakes in Alaska (Fig. 1 and 2) suggest that here also salmonids are homing to specific spawning areas.

Several different types of spawning grounds exist within the lakes studied. Sockeye salmon spawn in tributary streams, along lake beaches, and in the outlets of both lakes. Some areas are occupied early in the season, some during mid season, and others late in the season. This pattern of specific area occupation follows the same time and location sequence within a few days year after year. Spawning runs of sockeye salmon appear then to be separated at least into gross groups at both lakes by time and by physical distance. Thus, different tributary and outlet spawners possibly represent discrete stocks.

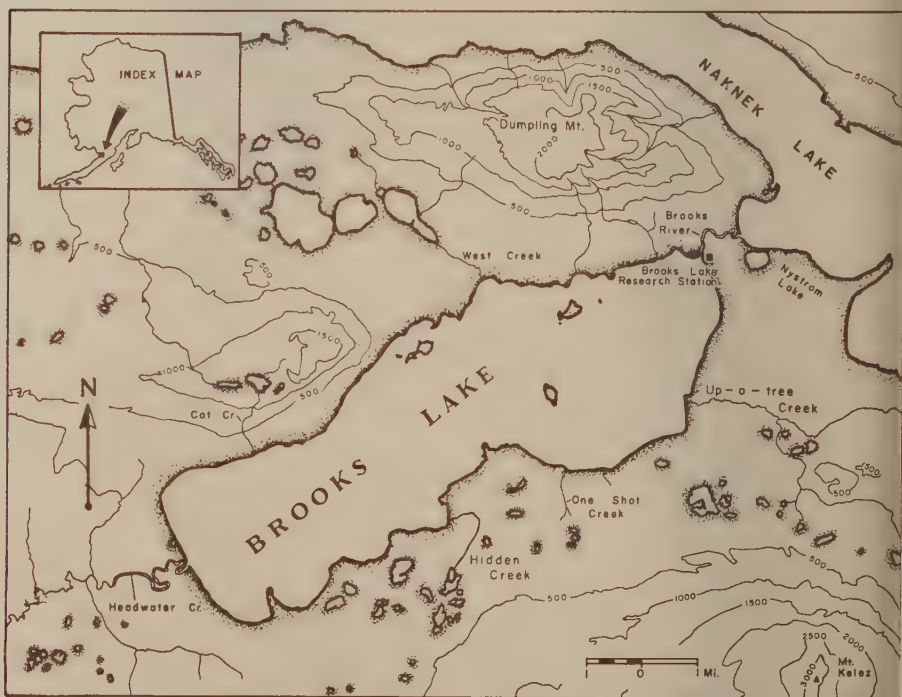


FIG. 1. Brooks Lake, Alaska, showing major sockeye salmon spawning tributaries and the outlet, Brooks River.



FIG. 2. Karluk Lake, Alaska, showing major sockeye salmon spawning tributaries and the outlet, Karluk River.

During 1959, length measurements were taken from spawning female sockeye salmon occupying 13 lateral streams tributary to Karluk Lake at the same time of the season. Significant differences at the 95% confidence level in mean lengths among streams with similar physical characteristics suggest that spawning stocks were apparently homing to specific tributaries.

With this background knowledge, we studied homing by sockeye salmon at Brooks and Karluk Lakes in 1960 and at Karluk Lake in 1961. Our major objective was to determine the discreteness, if any, of sockeye salmon stocks by examining the degree of preference to spawn in particular areas. Studies at Brooks and Karluk Lakes dealt with three problems related to this objective: Do sockeye salmon orient to particular spawning tributaries in small lake systems? If so, how tenacious is this preference? Finally, are sockeye salmon homing for particular spawning tributaries and beaches when they enter the lakes, or are they conditioned to particular tributaries after they reach the lakes? The findings of these studies and their biological and management implications are discussed in this paper.

BROOKS LAKE EXPERIMENTS

EXPERIMENTAL DESIGN

Adult sockeye salmon begin to congregate around the mouths of Brooks Lake tributaries and Brooks Lake outlet soon after entering the lake. This congregation occurs during the period of maturation just before they enter the tributaries to spawn. In the Brooks Lake study, samples of these fish were seined, and random groups from each sample were marked with distinctive tag combinations. One group was released into the original donor congregation as a control; the other group, into congregations near other spawning areas. Tributary preference was determined by analyzing the distribution to the various spawning areas of fish from each group. The salient comparisons of recoveries are between control and distributed groups of fish.

METHODS

Samples of 100 to 200 sockeye salmon were seined from congregations at the mouths of three tributaries, Up-a-tree, One Shot, and Hidden Creeks, and also at the outlet of Brooks Lake, Brooks River (Fig. 1). Certain features of these and of two Karluk Lake streams are given in Table I. Fish used in the

TABLE I. General features of sockeye salmon spawning tributaries at Brooks and Karluk Lakes, Alaska.

Stream	Length suitable for spawning	Average width spawning area	Average water depth	Average flow June-August
<i>Brooks Lake</i>	<i>miles</i>	<i>feet</i>	<i>inches</i>	<i>cfs</i>
Up-a-tree Creek	6	15	12	15
One Shot Creek	4	12	10	12
Hidden Creek	2	10	12	11
Brooks River	1	120	30	350
<i>Karluk Lake</i>				
Meadow Creek	$\frac{1}{2}$	14	10	13
Grassy Point Creek	$\frac{1}{2}$	12	10	12

control and the distributed-fish groups were captured and handled in the same way. Dip net loads of seined fish were placed alternately into two holding nets and were removed alternately from each holding net for tagging, regardless of sex.

Fish marked for redistribution were transported by boat in large tubs as rapidly as possible with frequent changes of water. Fish in the same experiment marked for release at the donor site were released at the time that redistributed fish were released.

The spawning destination of tagged fish was determined by the operation of weirs on Hidden Creek and Brooks River and by stream and lake beach surveys on the other known spawning grounds. The weir on Brooks River is at the lake outlet.

Twenty-two combinations of different colors and sizes of Petersen disk tags were used, and 985 fish were tagged. These 22 combinations comprised 8 experiments, each containing at least 2 groups. All fish in each group in a particular experiment came from the same seine haul. Tagging and recovery data for each group of sockeye salmon tagged in the Brooks Lake experiments are given in Table II.

Of the 985 fish released, 817 or about 83% were observed subsequently (Table II). Observers at the fish weirs counted 227 tags at Hidden Creek and 334 at Brooks River. The remaining 256 tags were counted on stream and lake beach surveys of all known spawning areas. Because fish from the same experimental group with identical tag combinations could not be distinguished on repeat surveys, recoveries of a particular tag combination equal the highest count obtained on any one survey at a particular stream and are not the cumulative count over several surveys. This fact combined with the virtually 100% recovery of tagged fish entering weired areas and the survey difficulties on large and turbid Headwater Creek must account for the range of per cent recoveries from 52 to 100. Surveys were made on foot on three of the unweired tributaries, One-Shot, Up-a-tree, and Headwater Creeks, and by boat along the lake beach spawning areas. Four tagged fish were recovered in gill nets around the mouth of West Creek (Fig. 1).

Mortality from tagging was negligible, as evidenced by generally high recovery. All fish in Groups 2, 3, 8, and 11 were accounted for (Table II), and more than 90% in Groups 10, 16, 17, 18, and 22.

Tagged fish were apparently not delayed in occupying the spawning grounds. Tagged to untagged fish ratios among spawners in Up-a-tree Creek, One Shot Creek, and Hidden Creek did not shift throughout the spawning season but remained constant.

Finally, tagging did not seem to affect the spawning behaviour of salmon. Tagged males spawned with untagged females, and tagged females with untagged males. Tagged males often attended untagged pairs, and in at least two instances, both members of a spawning pair were tagged.

TABLE II. Data on catching, tagging, and recovering sockeye salmon in the Brooks Lake experiments, 1960.

Experiment no.	Group no.	Captured		No. tagged	Tag color combination ^a	Released		No. tagged and released	No. recovered on:						Total recovered			
		Date	Site			Date	Site		Brooks River	Up-a-tree Creek	One Shot Creek	Hidden Creek	Headwater Creek	West Creek	Lake Beach	No.	%	
1	1	July 23	Brooks River	50	Y-Y	July 23	Up-a-tree Creek	50	39					2		41	82	
1	2 ^b	July 23	Brooks River	17	Y-W	July 23	Brooks River	17	17 ^a							17	100	
2	2	July 27	Brooks River	49	Y-R	July 27	Brooks River	49	48 ^a					1		49	100	
2	4	July 27	Brooks River	50	Y-B	July 27	One Shot Creek	50	39							39	78	
2	5	July 27	Brooks River	50	W-Y	July 27	Up-a-tree Creek	50	39	1					1	41	82	
3	6	July 28	Up-a-tree Creek	49	R-Y	July 28	Hidden Creek	49	1	34		1				36	74	
3	7 ^b	July 28	Up-a-tree Creek	50	W-R	July 28	Up-a-tree Creek	50	50				1			44	88	
3	8	July 28	Up-a-tree Creek	25	R-W	July 28	Brooks River	25		24	1					25	100	
3	9	July 28	Up-a-tree Creek	50	B-Y	July 29	One Shot Creek	50		35	1		1			37	74	
4	10	Aug. 1	Hidden Creek	50	R-R	Aug. 1	One Shot Creek	50	1			45				46	92	
4	11 ^b	Aug. 1	Hidden Creek	50	B-W	Aug. 1	Hidden Creek	50				48				50	100	
5	12	Aug. 2	One Shot Creek	50	B-R	Aug. 2	Up-a-tree Creek	50	1	15	17	3				38	72	
5	13 ^b	Aug. 2	One Shot Creek	50	R-B	Aug. 2	One Shot Creek	50	1	12	17	2				32	64	
6	14	Aug. 3	One Shot Creek	50	W-B	Aug. 3	Hidden Creek	50		8	14	2	2			26	52	
6	15	Aug. 3	One Shot Creek	38	B-B	Aug. 3	Brooks River	38	5	4	12		2			23	61	
7	16	Aug. 5	Hidden Creek	48	R-Yg	Aug. 5	Brooks River	48	4			43				47	98	
7	17	Aug. 5	Hidden Creek	50	R-Yr	Aug. 5	Up-a-tree Creek	50	3			45				48	96	
7	18 ^b	Aug. 5	Hidden Creek	50	Yg-R	Aug. 5	Hidden Creek	50	8			37		1	2	48	96	
8	19	Aug. 11	Brooks River	49	B-Vr	Aug. 11	Hidden Creek	49	34	1						35	71	
8	20 ^b	Aug. 11	Brooks River	50	Yr-B	Aug. 11	Brooks River	50	43				1			44	88	
8	21	Aug. 11	Brooks River	40	B-Rr	Aug. 14	Midlake	40	33						1	84	85	
8	22 ^b	Aug. 11	Brooks River	20	Rr-B	Aug. 14	Brooks River	20	17				1		1	19	95	
Totals:									985	334	177	62	227	8	4	5	817	83

^aLeft side given first. Colors are designated R (red), Y (yellow), G (green), B (blue), and W (white). Small letter denotes small tag on top of large tag.^bControl experiment.^cEighteen counted. Miscount at Brooks weir probably due to heavy salmon movement up and down through the weir gates at times.^dFifty counted. Miscount at Brooks weir.

RESULTS

There was no prior evidence that all salmon congregating near a particular tributary or Brooks River were destined to enter that area to spawn. Thus, tests for spawning area preference involved comparing within each experiment the tag recoveries from spawners transported to other areas with those from spawners left at the capture sites as controls. The eight experiments will be discussed in their increasing order of complexity. Detailed data are given for each experiment in Table II.

Experiment 4 (Fig. 3) involved fish seined at Hidden Creek. One group of 50 was released there as a control (Group 11), and a second group of 50 was transported to and released at the mouth of One Shot Creek (Group 10) about 3 miles away. All control fish were eventually accounted for on spawning areas, and all but two spawned in Hidden Creek. Forty-six of the fish transported to One Shot Creek were accounted for, and only one did not return to Hidden Creek to spawn. The almost complete choice by fish in both groups to spawn in Hidden Creek (93 of 96 fish recovered) suggests a strong tributary preference. Apparently the congregation around the mouth of Hidden Creek at the time of

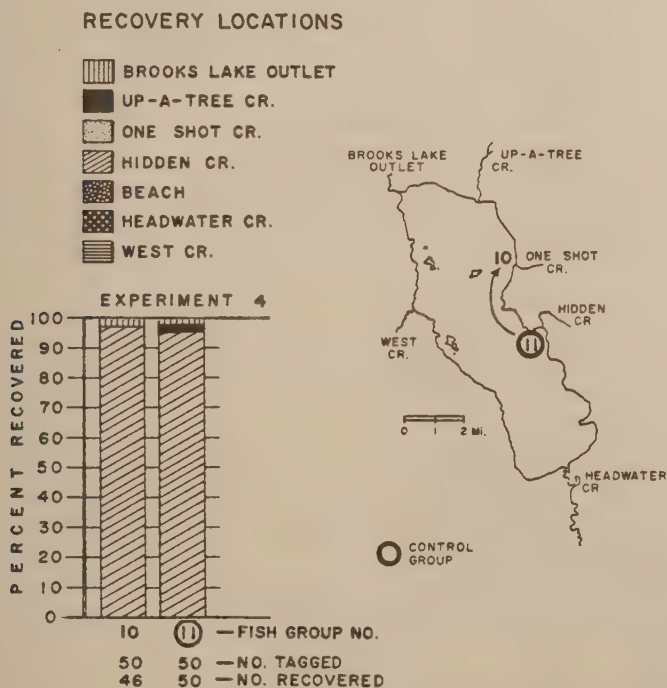


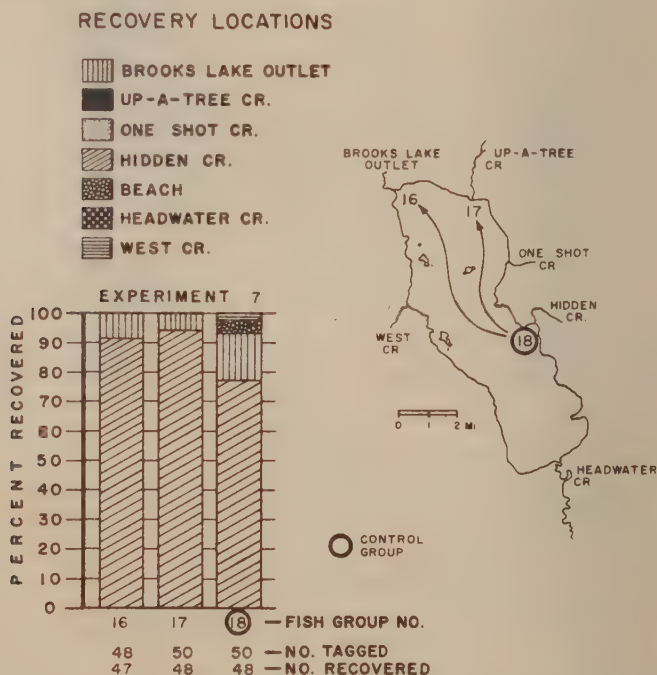
FIG. 3. Destination of adult sockeye salmon spawners in experiment 4 seined around the mouth of Hidden Creek; Group 11 was released as a control at Hidden Creek. Group 10 was transported and released at One Shot Creek.

seining was essentially homogeneous, consisting primarily of fish destined to spawn in Hidden Creek.

Experiment 7 (Fig. 4) consisted of two distributed-fish groups and one control group, and Experiment 3 (Fig. 5) consisted of three distributed-fish groups and one control group. The highly similar distribution in the spawning areas of fish from the control and distributed groups within each experiment again reflects strong tributary preference. It also appears that both congregations at the time of seining were essentially homogeneous since most fish spawned in the creek near where they were first captured.

In Experiments 1, 2, and 8 (Fig. 6-8) almost all of the fish either stayed in the outlet area (Brooks River) or returned there to spawn, indicating that the congregation at the outlet was virtually homogeneous. Results from all three experiments again demonstrate the strong preference of sockeye salmon for a particular tributary stream.

In Experiment 8 (Fig. 8) individual fish in Group 21 were distributed at 200- to 300-yard intervals down the middle of Brooks Lake to prevent schooling immediately after release. This group and its control, Group 22, were kept in



RECOVERY LOCATIONS

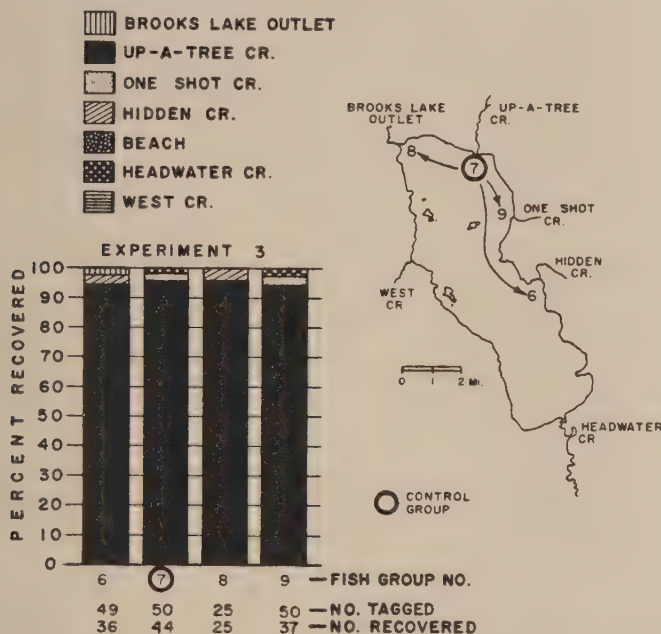


FIG. 5. Destination of adult sockeye salmon spawners in experiment 3 seined around the mouth of Up-a-tree Creek. Group 7 was released as a control at Up-a-tree Creek. Group 8 was transported and released at Brooks River. Group 6 was transported and released at Hidden Creek. Group 9 was transported and released at One Shot Creek.

holding nets at Brooks River for 2 days before being released. Neither the scattering nor the delaying caused deviation from the behaviour shown by Groups 19 and 20 (Experiment 8) which were handled in the manner previously described.

The obvious conclusion from these experiments is that sockeye salmon have an extremely strong degree of preference for spawning in particular lake tributaries or the lake outlet. But are they conditioned to specific areas during congregation as adults around stream mouths prior to spawning, or are they homing? Two additional experiments at Brooks Lake bear directly on this point. Experiment 5 (Fig. 9) carried out at Brooks Lake showed a pattern of distribution of sockeye salmon to spawning areas different from that shown in other experiments (Fig. 3-8). In Experiment 5, two groups of fish were seined and tagged from the congregation near One Shot Creek. Group 12 was transported 2 miles to the congregation off Up-a-tree Creek, and Group 13 was left at One Shot Creek as a control. About 40% of Group 12 stayed at Up-a-tree Creek to spawn, and 48% returned to the donor stream to spawn. The control

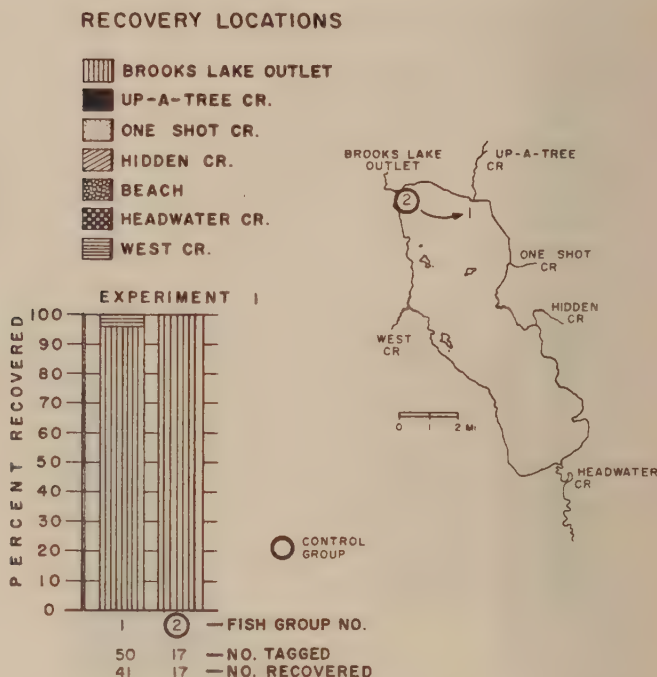


FIG. 6. Destination of adult sockeye salmon spawners in experiment 1 seined around the outlet of Brooks Lake. Group 2 was released as a control at the river. Group 1 was transported and released at Up-a-tree Creek.

(Group 13) distributed itself in about the same manner; of the control group seined off One Shot Creek and left there, 38% left the stream and migrated to Up-a-tree Creek to spawn. This evidence indicates that the belief that sockeye salmon develop a strong orientation to a tributary only after coming into its influence prior to spawning probably is incorrect. Actually, the results of Experiment 5 further substantiate the hypothesis of stock discreteness at the small tributary level. Unlike the homogeneous congregations of fish found near other spawning areas, the congregation at the mouth of One Shot Creek at the time of seining was a mixture of two major stock groups. Fish in one segment were destined to spawn in the stream near where they were schooled. Fish in the second segment, destined to spawn in Up-a-tree Creek and apparently still searching for their home stream, had stopped at the mouth of One Shot Creek. Not receiving the proper stimulus from One Shot Creek, they moved on to spawn in Up-a-tree Creek.

Experiment 6 (Fig. 10) involved two groups of fish seined at One Shot Creek the day after fish for Experiment 5 were captured. One group was transported 3 miles to Hidden Creek, the other 4 miles to Brooks River. There was no

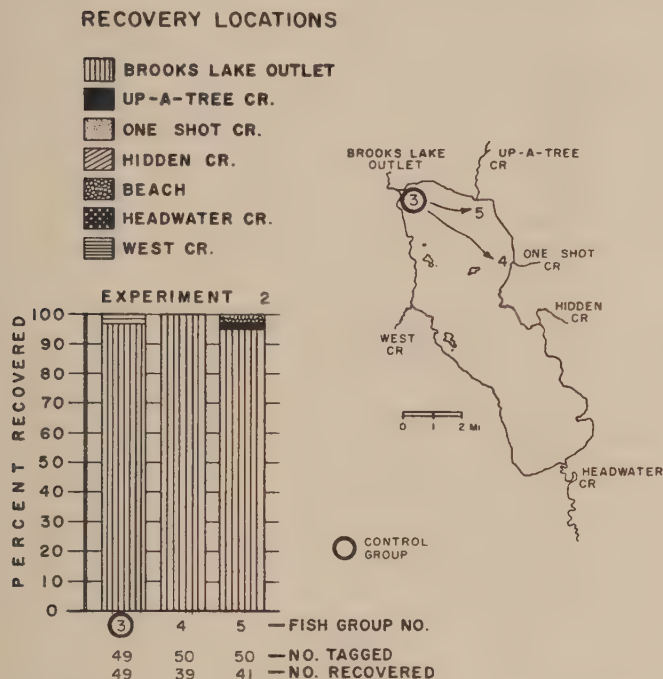


FIG. 7. Destination of adult sockeye salmon spawners in experiment 2 seined around the outlet of Brooks Lake. Group 3 was released as a control at the outlet. Group 5 was transported and released at Up-a-tree Creek. Group 4 was transported and released at One Shot Creek.

control group in Experiment 6. As in Experiment 5 (Fig. 9), about 50% of the fish in both groups returned to spawn in One Shot Creek. Many of the remaining 50% left Hidden Creek and Brooks River and spawned in Up-a-tree Creek. The appearance of five spawners in the outlet from the group released at Brooks River and of none from the group released at Hidden Creek was considered to be sampling error related to selection of fish for each group. At least one fish each from Groups 12 and 13 released the previous day (Experiment 5; Fig. 9) spawned in Brooks River. Apparently some Brooks River fish were present in the congregation off One Shot Creek both days.

Results of Experiment 6 substantiate those of Experiment 5 in showing that sockeye salmon were homing to specific tributaries rather than developing a strong orientation to a tributary only after coming into its influence prior to spawning. In fact, fish in Experiment 6 were neither seined nor released at Up-a-tree Creek. Yet many fish migrated there to spawn. It should be pointed out here again that the comparison between the distribution of recoveries for experimental and control groups is the salient comparison. It is therefore

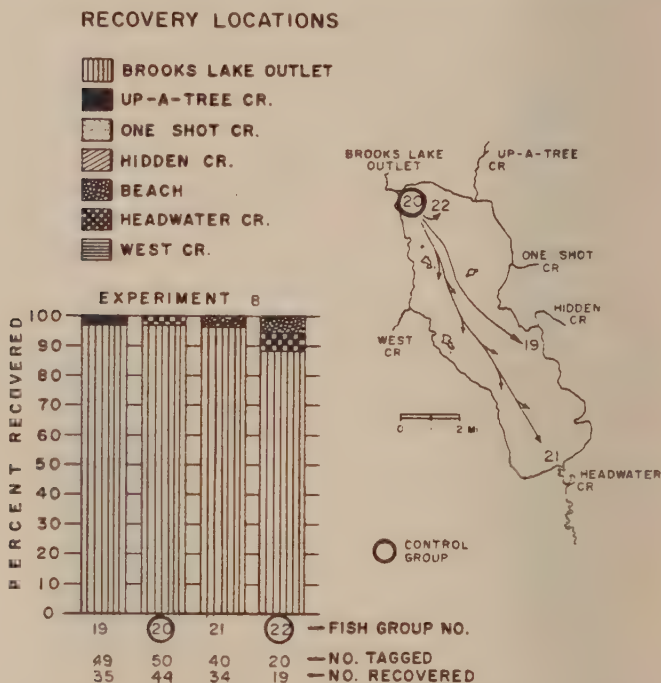


FIG. 8. Destination of adult sockeye salmon spawners in experiment 8 seined around the outlet of Brooks Lake. Groups 20 and 22 were released as controls at the outlet. Group 19 was transported and released at Hidden Creek. Fish in group 21 were scatter-released down the middle of Brooks Lake.

immaterial in the Brooks Lake studies whether the congregation of salmon from which the fish were seined was homogeneous (composed of salmon destined for one spawning area) or heterogeneous (composed of salmon destined for several spawning areas).

KARLUK LAKE EXPERIMENTS

The objective of the first Karluk Lake study was to determine the tenacity of tributary preference of sockeye salmon denied access to their preferred tributary.

In the summer of 1961 adult sockeye salmon of both sexes were captured at a weir trap as they first entered the mouth of the tributary, Meadow Creek (Fig. 2). The trapped fish were placed alternately in either an experimental or a control group. Each fish was tagged with an individual tag combination involving color, size of tag, and placement — either anterior or posterior to the dorsal fin. A group of 100 fish each from the experimental and control groups was tagged and returned to the lake. As the tagged fish entered the weir trap on subsequent attempts to enter the tributary, the individual tag combination and time and date of the attempt were recorded. Control fish that entered the

RECOVERY LOCATIONS

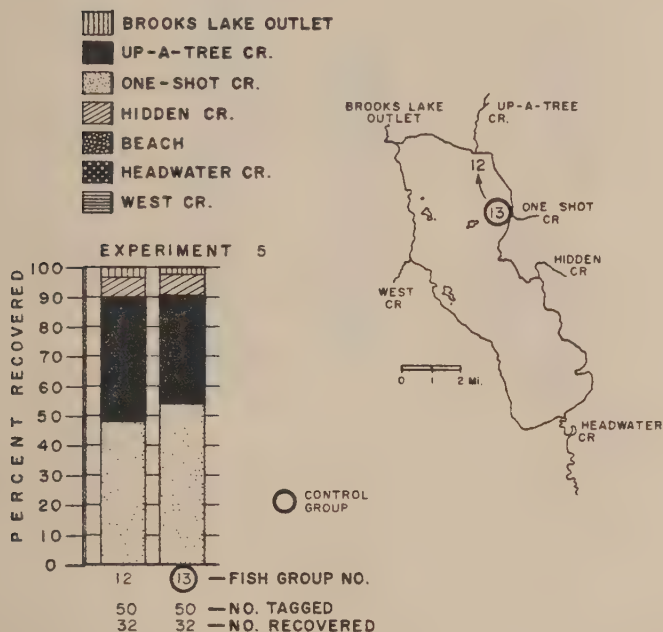


FIG. 9. Destination of adult sockeye salmon spawners in experiment 5 seined around the mouth of One Shot Creek. Group 13 was released as a control at One Shot Creek. Group 12 was transported and released at Up-a-tree Creek.

tributary were placed upstream and allowed access to the spawning beds. Experimental fish, on the other hand, were repeatedly returned to the lake. This procedure continued until tagged fish could no longer be recovered and spawning was completed within the tributary. Daily tag surveys of other spawning tributaries were conducted to record movement and utilization of these areas by individual experimental and control fish.

During this study, 99% of the control fish and 95% of the experimental fish were recovered and released one or more times (Fig. 11). After the initial release of all tagged fish back into the lake, 94% of both groups re-entered Meadow Creek, the apparent home stream, before attempting to enter any other spawning tributary (Fig. 11). Location of the last recoveries for each fish shows that 95% of the control group spawned in the apparent home stream, and 79% of the experimental group continued to attempt to enter Meadow Creek until they disappeared. Of further interest is the average of 11 attempts per experimental fish to enter Meadow Creek over the study period. Thus, the great majority of experimental fish, though completely blocked from their apparent home stream, continued re-entry attempts until disappearance and were never observed

RECOVERY LOCATIONS

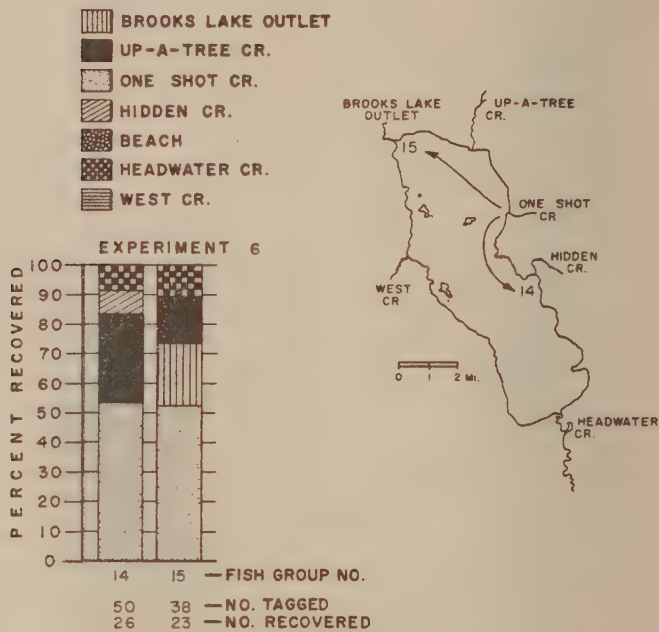


FIG. 10. Destination of adult sockeye salmon spawners in experiment 6 seined around the mouth of One Shot Creek. Group 15 was transported and released at Brooks River. Group 14 was transported and released at Hidden Creek.

on alternative spawning grounds even though observations were continued throughout the spawning period in the area of investigation.

Another study was carried out at Karluk Lake in 1961 to investigate further the possibility that fish might still become conditioned or oriented to a specific tributary after coming under its influence prior to spawning. This study entailed an attempt to influence the tributary selection of a group of salmon by holding them under the influence of a particular tributary during their lake maturation period.

Six hundred sockeye salmon adults of both sexes were captured as they first entered the lake through the Karluk weir trap and were alternately placed in three groups of 200 fish each. The control group was tagged with yellow Petersen disk tags and released. Fish from this group were expected to proceed in a normal manner to their specific spawning gravels. Their appearance on the spawning grounds would be used as a signal for releasing the two experimental groups. Fish in experimental Group 1 were tagged with red Petersen disk tags and placed in a large holding pen. Fish in experimental Group 2 were tagged with white Petersen disk tags and placed in an identical holding pen. Both holding pens were then towed up the lake halfway between the outlet and Grassy

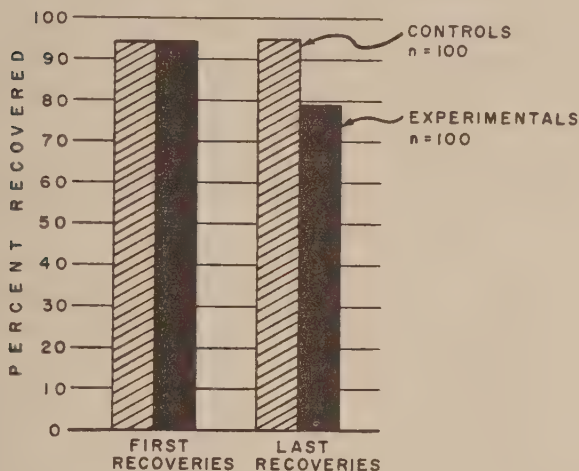


FIG. 11. First and last recoveries in Meadow Creek of tagged adult sockeye salmon in home stream preference study, Karluk Lake. Control fish were allowed free passage into Meadow Creek. Experimental fish were returned to the lake after every attempt to enter Meadow Creek.

Point tributary (Fig. 2). Fish in experimental Group 1 were then returned to the outlet of Karluk Lake and held until ready to spawn. Experimental Group 2 fish were towed to Grassy Point and held under the influence of Grassy Point Creek water during maturation. Thus, experimental Groups 1 and 2 were given the same treatment, with the exception of area of confinement. Group 1 was held under the influence of the lake outlet water rather than the water of a specific tributary.

The three groups were tagged on June 14 and 15. By late morning of June 16 both groups being retained were towed in the pens to their respective holding sites, and the holding pens were securely anchored into place. Throughout the retention period of 18 days, both pens were checked twice daily. The fish in both pens soon showed signs of abrasion from contact with the hardware cloth sides. Both groups also suffered mortality before release — 19% of experimental Group 1 and 21.5% of experimental Group 2.

On June 28 a small hole was discovered in the holding pen at Grassy Point and was repaired. Less than one dozen fish had escaped. Three of the escapees and the first of the control group fish were observed during a stream survey count of spawning adults on July 1. On July 3 both experimental groups of fish were released at their holding sites. Tagged fish from each of the three groups were recovered on subsequent weekly stream surveys from the spawning areas then being utilized. The first recoveries occurred on July 7 during the first stream survey after the release. On this date fish from all three groups were observed on the spawning beds. The last recovery was one from the control group observed 4 weeks later on August 5.

Tag recoveries at the test stream weir show that fish held at the mouth of Grassy Point Creek, experimental Group 2, did not enter that tributary to spawn in any greater frequency than fish in the other two groups. Percentage recoveries at Grassy Point were 9.1, 9.1, and 15.2 for the two experimental groups and the control group, respectively. The preference of fish in experimental Group 2 to spawn in Grassy Point Creek was not increased by the conditioning treatment.

DISCUSSION

HOMING

The foregoing series of studies demonstrate: (1) sockeye salmon show a strong and tenacious specific spawning tributary preference within a small lake system, and (2) this preference is not the result of conditioning after the fish enter the lake. At Brooks Lake some fish grouped around tributary mouths did not necessarily spawn there. But the salient point is that tagged fish in groups transferred to other lake areas did ultimately spawn in the same areas and in the same proportions as did tagged fish left at capture sites as controls. At Karluk Lake most fish continued to attempt re-entry of their home tributary if prevented from doing so. Also at Karluk Lake, tributary selection of sockeye salmon was not influenced by conditioning. This cogent evidence indicates that sockeye salmon are predisposed to spawn in a particular tributary prior to entering a lake system and are indeed homing.

SEARCHING, OVERSHOOTING, AND STRAYING

Little is known about the routes of sockeye salmon from the time they enter Brooks and Karluk Lakes until they enter spawning areas. During this period, fish may be seen on days when the water is calm in almost any part of the lake. Fish in groups around the mouths of tributaries gradually increase in numbers during the maturation period. Such behaviour conforms to the searching and sorting process of home tributary selection discussed by Hasler and Wisby (1951).

On two occasions at Brooks Lake, fish with particular tag combinations were sighted around the mouths of tributaries other than where they were captured or released. A Y-W tagged fish in Group 2, which was seined at the outlet of Brooks Lake and left there as a control on July 23, was seen at the mouth of One Shot Creek on August 2. No Y-W tags were recovered in One Shot Creek. All fish in Group 2 eventually returned to Brooks River. Another fish seined at Hidden Creek and tagged R-R (Group 10) was released at One Shot Creek on August 1 and was seen off Up-a-tree Creek the same afternoon. No R-R tags were recovered in Up-a-tree Creek. Both of these incidents are considered to be related to the searching out of the proper stimulus by which salmon recognize their home stream.

The phenomenon of fish passing by a spawning tributary or up through a spawning area and then returning downstream to spawn may be termed "overshooting". The Y W tagged fish from Group 2 is a specific example. Overshooting in general is demonstrated in Brooks River. Thousands of sockeye salmon that pass up through Brooks River into Brooks Lakes every year even-

tually return to spawn in the river. Some of the fish in every experiment seined around the mouths of lake tributaries eventually spawned in Brooks River, so at least some of the Brooks River fish came within the direct influence of other spawning areas and rejected them.

Finally, some evidence on the degree of straying between tributary stocks was gathered in our studies. In Experiments 1, 2, 3, 4, 7, and 8 at Brooks Lake, most fish went to one particular tributary to spawn. An average of about 6.8% of the fish chose alternative tributaries. We interpret this as representing the average maximum degree of straying between tributary stocks in Brooks Lake. Indeed, it might be quite a bit less than this, because some fish choosing alternative tributaries in the experiments may well have been homing there anyway. In the home stream rejection experiment at Karluk Lake, 5% of the control fish first entering one tributary eventually left and entered an alternative tributary; 2% ultimately returned to spawn in the first tributary. Thus, straying was actually no greater than 3%. Lindsey *et al.* (1959) found that rainbow trout, once they had spawned in the outlet of Loon Lake, B.C., almost unerringly (99.6%) returned to the outlet area to spawn for the second or third year. They also found that about 94% of the fish hatched in the outlet returned there for their first spawning. Cope (1957) found that about 97% of the cutthroat trout in Yellowstone Lake spawning a second time returned to the tributary of previous spawning. Vernon (1957) found that less than 3% of the 1131 kokanee examined in Kootenay Lake, B.C., spawned in an area in the lake other than that of their natal origin.

BIOLOGICAL AND MANAGEMENT IMPLICATIONS

These findings reveal that each lake tributary probably supports discrete stocks or groups of stocks. Such discreteness of stocks has important biological and management implications.

Large spawning runs are likely to be complex heterogeneous assemblages of discrete stocks. The Brooks River run is only one of several important runs in the overall run of the Naknek River system. Yet, Brooks River serves as a route for stocks going to five tributaries, one beach spawning area in Brooks Lake, and Brooks River itself. The evidence suggests that every major lake tributary and beach spawning area in the entire Naknek Lake system, of which Brooks Lake is a part, may have one discrete stock or more. This same stock diversity probably holds true for the 16 spawning tributaries and several beach spawning areas in the Karluk Lake system.

Such diversity of stocks within sockeye salmon runs has long been considered probable. Thompson (1945) based his interpretation of the effect of the obstruction at Hell's Gate on the Fraser River on sockeye salmon upon the concept of races. Sockeye salmon stock diversity in the Fraser River run has been examined at three levels: upper and lower system groups (Thompson, 1945); major river groups (Killick, 1955); and major groups within one large river system, the Harrison River (Schaefer, 1951). It also seems reasonable to expect discreteness of sockeye salmon stocks down to the level of individual tributaries within each large river system.

Different interpretations of the well-known Karluk River sockeye salmon run occur in the literature. Barnaby (1943) described the run as bimodal with a spring run and a fall run that overlap to a limited extent. He observed some differences in utilization of various spawning areas by salmon in the two runs, and even where the same area was used by both spring and fall run salmon, there were great differences in time of spawning. This last feature would completely prevent breeding between spawners in different runs and suggests the existence of at least two stock groups.

Rounsefell (1958) believed that all Karluk sockeye salmon belonged to the same population or race, giving as his reasons the following: (1) the modes of abundance in the total annual run could be caused by the times when different age combinations of smolts and ocean-age fish return, and (2) significant correlations occur between fish of the same brood that return at different ages in different times of the season.

Ricker (MS, 1959) questions these two arguments. He first says that variability in abundance in a parallel fashion by different ocean groups having the same number of freshwater years "... might reflect variations in survival conditions in the lake during their common freshwater life." Ricker then points out that "The attempt to relate variations in numbers of spring-run and fall-run $5_{3's}$ to temperature during season of return produced only a weak and non-significant correlation (0.28)."

Owen *et al.* (MS, 1962) present new information on differences in time of spawning and place of spawning between the Karluk spring and fall runs. They discuss the possibility that discrete stocks are associated with particular spawning areas and conclude that differential fishing of the stocks may have contributed to the decline of part of the Karluk run.

The findings at Brooks and Karluk Lakes support the general contention that the run into a lake may be composed of more than one stock. Modes in the annual Karluk run (Barnaby, 1943) probably reflect the seasonal appearance of early and late spawning stocks.

Separation of sockeye salmon spawning stocks by strong homing behaviour might under certain circumstances cause some genotypic divergence. Vernon (1957) found some genotypic divergence between kokanee salmon in Kootenay Lake, B.C. He suggests that some adaptive genotypic divergence has also occurred between many sockeye salmon stocks. Vernon notes that large-scale rehabilitation programs where sockeye salmon have been transplanted to new areas even within the same river system (Foerster, 1946) have been generally unsuccessful.

Such discreteness of stocks obviously is of great significance to the fishery manager. In rehabilitation programs involving the establishment of new populations or the strengthening of weak ones by transfer of fish, adaptability of the stocks to rather local environmental conditions must be considered. In management of the fishery, or more to the point, in management of the escape-ment, proper numbers of spawners from each important stock must be allowed to escape. A final consideration pointed out by Thompson (1959) is that some

fish from all stocks should be allowed to escape so that the wide range of stock adaptation to varying environmental conditions can be maintained.

SUMMARY

1. At Brooks Lake in 1960, 985 adult sockeye salmon were seined from schools around stream mouths prior to the spawning period and were arbitrarily placed into 22 groups.

2. Each group was tagged with Petersen disk tags of a particular color combination. Some groups were released into their donor schools; others were released into schools around other stream mouths.

3. Eighty-three per cent of the tagged fish were recovered at weirs and on lake and stream surveys.

4. Distribution of spawning areas of tagged sockeye salmon in control and transported groups was almost identical. Thus, it was demonstrated that the sockeye salmon in Brooks Lake have an extremely strong preference to spawn in a particular tributary.

5. In 1961 at Karluk Lake, adult sockeye salmon were experimentally prevented from entering their preferred spawning tributary. Only 5% of the experimental group initially chose alternative spawning areas. Seventy-nine per cent of the fish persisted in attempting to re-enter their blocked tributary until they disappeared.

6. A final study at Karluk Lake in 1961 tested the effects of capturing adult sockeye salmon as they entered the lake and holding them within the influence of a particular tributary until the spawning period.

7. After release no more fish from this group entered that particular tributary than did fish from a group held at the lake outlet or a third group tagged and immediately released at the lake outlet.

8. We interpret these findings as follows: (1) adult sockeye salmon at Brooks and Karluk Lakes have an extremely strong preference to spawn in a particular tributary; (2) this preference is tenacious and not easily altered by experimentally blocking the entrance to the preferred stream; and (3) these fish are homing to particular spawning areas in Brooks and Karluk Lakes, and their ultimate destination cannot be significantly altered by conditioning them to a particular spawning tributary after they have entered the lake.

9. The biological and management implications of the findings are discussed.

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This manuscript is dedicated to Mr Charles Y. Conkle, recent research biologist at Karluk Lake, whose untimely death ended a promising career in fishery biology.

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Mass Spawning Behavior of Sockeye Salmon in Brooks River, Alaska

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The spawning behavior of sockeye salmon in Brooks River, Alaska, was studied in 1957 and 1958. In both years, 3 successive waves of spawners occupied the gravels. Males spent about 5 days on the redd sites and females about 9 days. Both sexes dug redds, but females were considerably more vigorous and effective. Males defended spawning territories vigorously, but almost entirely against other males. Females defended territories against both males and females. When the male of a spawning pair disappeared, the female defended the redd against fish of either sex. Defense of the redd has obvious survival value if successive spawning reduces overall egg survival as a result of excavation of previously deposited eggs. Differences in the life-spans of males and females may cause erroneous estimates of sex ratios if counts are made of only the live or the dead fish during the spawning period.

INTRODUCTION

THE spawning period is a critical time in the life history of any species of fish but is particularly critical in Pacific salmon, *Oncorhynchus* spp. At that time, the filial generation must be seeded properly in the gravels of the selected spawning site to perpetuate the population successfully. This paper describes the spawning behavioral patterns of sockeye salmon, *O. nerka* (Walbaum), in Brooks River, Alaska. Results are discussed in terms of behavioral patterns contributing to successful spawning.

Literature on salmonid spawning behavior is relatively abundant: Briggs (1953), Fabricius (1951, 1953), Fabricius and Gustafson (1954), Jones and King (1949), and Wilimovsky and Freihofer (1957). Only three major scientific accounts dealing with sockeye salmon spawning behavior have been located: Burner (1951), Schultz and Students (1935), and Mathisen (1962). Minor notes have appeared in English and Russian scientific literature. Most of the references mentioned deal with the behavior of individuals or spawning pairs, and little has been reported on the relationships between spawners on the spawning grounds.

We made daily observations in 1957 and 1958 over a section of Brooks River where salmon had spawned for many years. Brooks River flows about 8,000 ft and empties into Naknek Lake. The Brooks River spawning population is one of the most important in the annual run that enters the valuable Bristol Bay fishery and escapes into the Naknek River system. The dy-

namic organization of the spawning population was studied in terms of timing, sex ratios, and density, and individual behavior was studied in terms of territorialism and redd construction.

METHODS AND MATERIALS

Brooks River is a cold clear stream averaging 100 ft wide and 2 ft deep. The flow during the spawning season is between 300 and 500 cfs. The gravel is loose and mostly from 1/8 in. to 3 in. in diameter.

The main study area was about 400 yards below Brooks Lake outlet in a section of the river where salmon habitually spawn. Quadrats were formed by driving aluminum stakes 15 ft apart along each side of the river and connecting opposite stakes with light twine marked at 15-ft intervals with small, colored cloth strips. This effectively divided the study area and facilitated redd location and orientation of spawning observations.

Spawning was observed on 47 days in 1957 and 37 days in 1958. To maintain uniformity and to take advantage of the best light conditions, most observations were made between 10:30 AM and 3 PM. Twenty-foot towers were installed along each bank of the study area. Equipment used by observers included Polaroid glasses, watch, binoculars, blank grid maps, and looseleaf notebook. Data were recorded in longhand in 1957 and on IBM Port-a-punch cards in 1958.

At the start of each daily observation period, the observer plotted the locations of all salmon in those squares clearly in view from the tower. Sockeye salmon on the

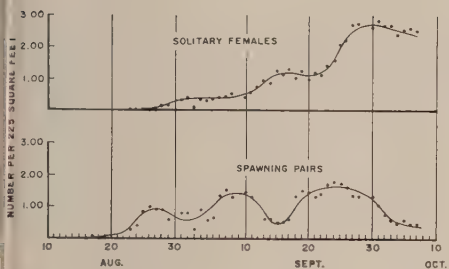


Fig. 1. Densities of spawning pairs and solitary females on sockeye salmon redd sites in Brooks River study area in 1957. (Curves fitted by inspection.)

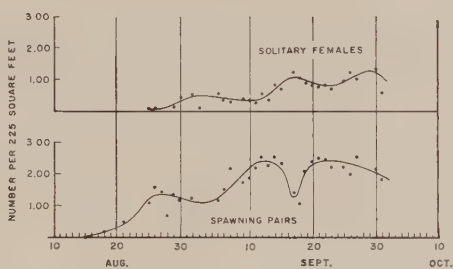


Fig. 2. Densities of spawning pairs and solitary females on sockeye salmon redd sites in Brooks River study area in 1958. (Curves fitted by inspection.)

spawning grounds usually fell into 3 categories: (1) Fresh males—males not paired with spawning females (most of the fresh males were jack [1 ocean year] salmon); (2) spawning pairs—pairs composed of a male and a female in residence over redd sites; and (3) solitary females—spawned females defending the redd sites after the males had disappeared.

Activity in specific squares was followed in 1957, and activity by specific salmon was followed in 1958. The following information was recorded during observations: (1) date of observation, (2) sky and water conditions, (3) location of observation in grid, (4) time at start and end of observation, (5) number of redd sites dug by each sex, and (6) number of defensive actions by each sex, including sex of the intruding salmon. (A "defensive action" is defined in the section on Spawning Behavior.)

Keeping track of a specific salmon throughout the spawning and postspawning periods depended on consistent identification. Some salmon were marked naturally by peculiar colorations, wounds, or distinctive fungus patches, and some were marked with Petersen disk tags. The latter, which were tagged upstream at a fish weir, would occasionally drop back down into the study area where their activities could be followed. In 1958, 88 salmon marked with various tag colors on different body positions were observed in a deep pool 80 yards below the study area. Some of them eventually spawned in the study area, and their spawning life-span was determined.

SPAWNING BEHAVIOR

Sockeye salmon first appear in Brooks River in late June. Most of the early mi-

grants enter Brooks Lake and spawn either in tributaries that enter the lake or along the lake beaches. After mid-July most sockeye salmon passing through Brooks River into Brooks Lake return to spawn in the river (Merrell, in press). Spawning began in Brooks River on 16 August 1957 and on 11 August 1958, and virtually all spawning was completed by the second week in October in both years.

Before they spawn, salmon congregate in dense schools along undercut banks and in deep holes. During this holding period they undergo transformations in appearance associated with sexual maturation. Most of the changes are sexually dimorphic and deal with body color and physiognomy (Schultz and students 1935).

Males and females move onto the spawning gravels as the actual spawning cycle begins. Spawning pairs are formed, redd sites are chosen, and redd building begins. Redd defense develops, and spawning occurs shortly. The redd is defended until the last fish of the spawning pair dies.

Daily counts in 1957 and 1958 of spawning pairs and of solitary females guarding redds in the Brooks River study area have been converted into densities, i.e., numbers of fish per grid square (Figs. 1 and 2). The density of spawning pairs over 200 or more ft² of spawning area reflects 3 cycles or waves. The 1957 data show this cyclic phenomenon clearly (Fig. 1). Low points between waves occurred around 2 and 16 September 1957 and 4 and 18 September 1958. In 1957, Merrell (in press) considered such environmental factors as water flows, water levels, and temperatures in Brooks River and found no relationship

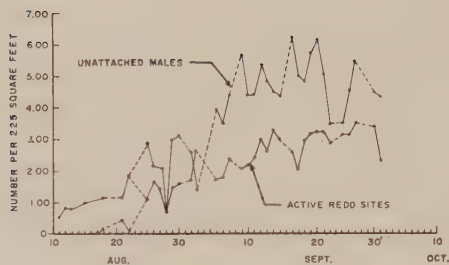


Fig. 3. Densities of active redd sites and unattached sockeye salmon males in Brooks River study area in 1958.

between them and the timing of spawning waves.

When the males of spawning pairs died, solitary females were left guarding the redds for a few days. Thus, the peak density of spawning pairs in a wave should be followed by a decline in spawning pairs and a rise in solitary females. Densities of solitary females in 1957 and 1958 (Figs. 1 and 2) increased sharply in every instance after the peak density of spawning pairs was reached.

Krogus and Krokhin (1948) counted up to 4 distinct spawning waves by sockeye salmon in one area of the Lake Dalnee, Kamchatka, spawning grounds. They also observed that the major disappearance of old spawners and recruitment of new spawners seemed to occur about the same time. In South Sakhalin, USSR, Dvinin (1952) found that at least 3 waves of pink salmon (*O. gorbuscha*) spawners occupied the principal grounds within a spawning period of $1\frac{1}{2}$ to 2 months. The reference here and in subsequent discussion to observations on pink salmon behavior are made for comparative purposes because of the general lack of information on sockeye salmon. The smaller average size of pink salmon must be taken into consideration in any comparisons.

Before leaving the results pertaining to wave spawning, we would like to point out that this phenomenon poses an interesting and basic question. Do these different spawning activity periods reflect the existence of different races? This question remains to be explored.

In Brooks River, the density of active redd sites, those actually occupied by females, increased throughout the 46-day spawning period in 1958 (Fig. 3). The

density was computed by summing the densities of spawning pairs and solitary females each day. The maximum density of active redd sites (3.55 per 225 ft²) was reached on 27 September. This represents a maximum of about 63 ft² per redd territory, or spawning space. The Brooks River study area is about 100 ft wide and 2 ft deep and has few underwater features that would isolate the redd sites visually.

One of us (Hartman) observed sockeye salmon spawners crowded into these tributaries in 1958, with many pairs spawning within a few feet of neighboring pairs. In contrast to this redd density value, the size of the redd territory in several small tributaries to Karluk Lake was often less than 9 ft². Karluk Lake is a highly important sockeye salmon producing system on Kodiak Island, Alaska.

Krogus and Krokhin (1948) observed that in different years female sockeye salmon occupied redd territories of several different sizes. In 1936 when spawning populations were quite large, the territories were about 8.6 ft².

McNeil (unpublished doctoral dissertation, University of Washington, 1962) estimated the number of female pink salmon spawning in Harris River and Indian Creek in southeastern Alaska in 1958, 1959, and 1960. Although the space occupied ranged from 22 to 83 ft², most females spawned in areas between 22 and 50 ft².

Female sockeye salmon were on the redd sites almost twice as long as males (Table 1). Males spent an average of 4.7 days on the redd sites and females an average of 8.9 days. These values may be low because pairs may not have been recorded until they had spent a day or most of a day on the redd site.

An indirect measure of the time spent on redd sites can be obtained from the lengths of spawning waves (Figs. 1 and 2). Data on the length of time on redds are given in Table 2. The average durations of the 3 waves each year for both years was 16.2 days for spawning pairs and 13.7 days for solitary females. Since a wave is dome shaped, the average length of life for a spawning pair cannot be greater than half the wavelength. Thus, the upper limits for average lengths of life are half the wavelengths, or 8.1 days for a spawning pair and 6.9 days for a solitary female. The lower limits, established by observing marked

TABLE 1. NUMBERS OF DAYS SPENT ON REDD SITES BY TEN MARKED PAIRS OF SPAWNING SCKEYE SALMON IN BROOKS RIVER STUDY AREA, 1958. On the last day of observation (1 October), the females of the ninth and tenth pairs were in very poor condition.

Day	Spawning Pair									
	1	2	3	4	5	6	7	8	9	10
1	♂ ♀	♂ ♀	♂ ♀	♂ ♀	♂ ♀	♂ ♀	♂ ♀	♂ ♀	♂ ♀	♂ ♀
2	♂ ♀	♂ ♀	♂ ♀	♂ ♀	♂ ♀	♂ ♀	♂ ♀	♂ ♀	♂ ♀	♂ ♀
3	♂ ♀	♂ ♀	♂ ♀	♂ ♀	♂ ♀	♂ ♀	♂ ♀	♂ ♀	♂ ♀	♂ ♀
4	♂ ♀	♂ ♀	♂ ♀	♂ ♀	♂ ♀	♂ ♀	♂ ♀	♂ ♀		♂ ♀
5	♀	♂ ♀		♀	♀	♀	♂ ♀		♂ ♀	♀
6	♀	♂ ♀	♀	♀	♀	♀	♀	♀	♂ ♀	♀
7		♂ ♀	♀	♀	♀		♀	♀	♂ ♀	
8		♀		♀	♀		♀	♀	♂ ♀	♀
9		♀			♀					♀
10		♀			♀			♀	♂ ♀	
11					♀				♀	
12					♀					
13					♀					
14					♀					

salmon, were 4.7 days for a spawning pair and 4.2 days for a solitary female. The actual time the redd is occupied lies somewhere between these limits, perhaps about 7 days for spawning pairs or males and 5 additional days for solitary females. Other evidence from Figs. 1 and 2 suggests that the average length of life of the spawning pair approaches half the average wave-

length. Heavy mortalities of males result in increases in the number of solitary females and decreases in the number of spawning pairs. These increases do not occur until after each wave peaks.

Krogus and Krokhn (1948) found that the life-span of sockeye salmon in the Lake Dalnee, Kamchatka, spawning grounds was 15 days. In a later paper (Krogus and

TABLE 2. ANALYSIS OF SPAWNING-WAVE DATA TO DETERMINE MEAN LENGTH OF TIME ON REDD SITES BY SPAWNING PAIRS AND SOLITARY FEMALES FOR 1957 AND 1958. The upper limit of the mean length of time spent on the redd (column 5) is calculated by dividing the total mean lengths for the two years in half. The data at the end of the 1958 season are not complete because observations were terminated before all fish had disappeared.

Year	Wave Number	Inclusive Dates Wave Occurred	Number Days	Upper Limit of Mean Length of Time on Redd
<i>Spawning Pairs</i>				
1957	1	17 Aug.-1 Sept.	16	8.5
	2	2-15 Sept.	14	
	3	16 Sept.-7 Oct.	22	
1958	1	18 Aug.-2 Sept.	16	7.5
	2	3-17 Sept.	15	
	3	18 Sept.-1 Oct.	14	
<i>Solitary Females</i>				
1957	1	25 Aug.-9 Sept.	16	7.5
	2	10-20 Sept.	11	
	3	21 Sept.-7 Oct.	17	
1958	1	25 Aug.-10 Sept.	17	6.5
	2	11-23 Sept.	13	
	3	24 Sept.-1 Oct.	8	

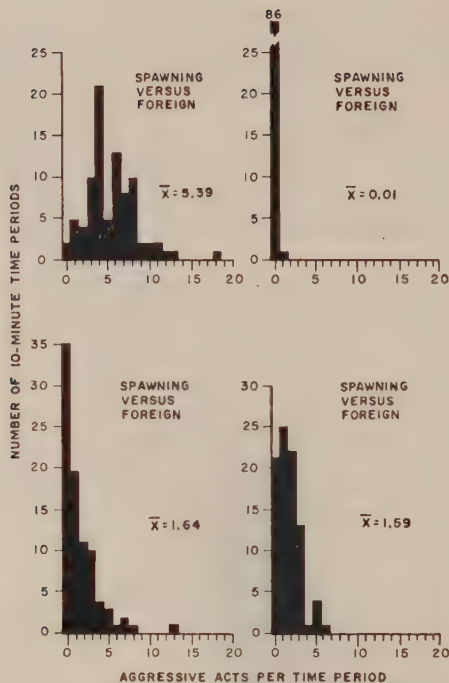


Fig. 4. Aggressive acts by spawning male and female sockeye salmon during 87 10-minute periods.

Krokhin 1956), they noted that females live longer and guard the redds for 10 to 20 days after spawning.

Killick (1955) found that the average life-span for sockeye salmon spawning in Forfar Creek, Fraser River, was about 13 days for females and 12 for males. He observed that the life-span for sockeye salmon spawning in the Adams River was substantially longer, 14 to 20 days.

Spawning pink salmon have life-spans similar to sockeye salmon. McNeil (unpublished doctoral dissertation) observed 38 tagged female pink salmon spawning in Harris River, southeastern Alaska, in 1960. They occupied the redd for an average of 10.82 days. Dvinin (1952) noted that the life-span of pink salmon females spawning in rivers in South Sakhalin did not exceed 20 days and was perhaps 14 days or less.

Aggressive acts, defined as "a male or female of a spawning pair making an obvious rush toward another salmon," were recorded in 1958 during 87 observation periods of 10 min each. These rushes normally

ended in chases of 5 to 15 ft. An aggressive act is considered a defense of the redd site.

Males defended the redd vigorously against other males, averaging 5.39 aggressive acts per time period (Fig. 4). They almost always tolerated other females, however, averaging only 0.01 aggressive act per time period. Females defended the redd vigorously against other females, averaging 1.64 aggressive acts per time period. They defended against other males on the average of 1.59 acts per time period. Solitary females defended redds extremely vigorously against all encroaching salmon regardless of sex, but not enough data were taken to document this phenomenon adequately.

Schultz and students (1935) reported defense of redds by both male and female kokanee (red salmon). Females generally defended the upper parts of a redd, while males defended the entire redd. Mathisen (1962), in his studies of sockeye salmon spawning behavior in Pick Creek, Alaska, reported that males assumed the major defensive responsibilities and guarded the redds against intrusion of strange fish of either sex. He also noted that females defended the redd mainly against other females and that few aggressive acts were made toward males. Kusnetzov (1928) observed that female pink salmon defended redds mainly against other females, not males. Smith (1941) observed male brook trout, *Salvelinus fontinalis*, defending their redds vigorously against intruding trout of either sex.

Unattached males always greatly outnumbered spawning pairs and solitary females except on 2 September 1958. Because of the large numbers of unattached males present, both members of each spawning pair spent considerable energy defending the redd territories.

We observed that both male and female salmon made digging or other redd-building movements in the redd sites. Digs recorded during 87 observation periods of 10 min each are summarized in Fig. 5. For example, in interpreting the figure, 5 digs were made by each female during 5 of the 87 time periods. Females averaged more digs per time period (1.56) than males (1.03). This agrees with the generally accepted theory that females build the redds. Nevertheless, males contributed materially to building the redds, although their digs were not as vigorous nor did they last as long as

hose by females. Schultz and students (1935) observed redd digging by male kokanee salmon, but most of it was by the females. Male pink salmon have also been observed digging in redd sites in Nile Creek, B. C. (Wickett 1959).

Much higher digging rates have been reported for sockeye and kokanee salmon. Mathisen (1962) observed a female for 160 min before her first spawning. During each 10-min observation period she dug at a fairly even rate for 6 or 7 times. Mathisen noticed a substantial increase in the digging rate after egg deposition which, however, tapered off until after the next egg deposition. Sheridan (1960) described this same phenomenon for pink salmon in southeastern Alaska. He noted the prespawning digging frequency was less than 1 dig per minute until egg deposition, when it was accelerated to about 8 per minute. Schultz and students (1935) watched 1 female kokanee make 20 digs in a little more than 8 min. Another made 68 digs in a little more than 18 min.

DISCUSSION

The features of sockeye salmon spawning behavior in a section of Brooks River reported here have several important biological implications.

Defense of the redd against foreign females must certainly favor egg survival. Superimposition of redds in some situations could cause substantial egg loss from the first seeding. Males defended against other males that entered the territory, either by accident, to participate in the courtship and spawning, or even to attempt to dislodge the original male from the territory. When a proportionately large number of other males are present, continual attempts to invade the territory interferes with the redd-building activities of the female, and she defends the redd to some extent against foreign males. After the males disappear, females defend the redds against spawners of either sex. When both spawners are gone, the redds become vulnerable to excavation by new spawners.

In Brooks River, excavation of redds by new spawners is indeed a threat. Three successive waves of spawners occupied the gravels in both 1957 and 1958. Krogus and Krokhn (1948) counted up to 4 spawning waves for some Lake Dalnee sockeye salmon, and Dvinin (1952) also observed

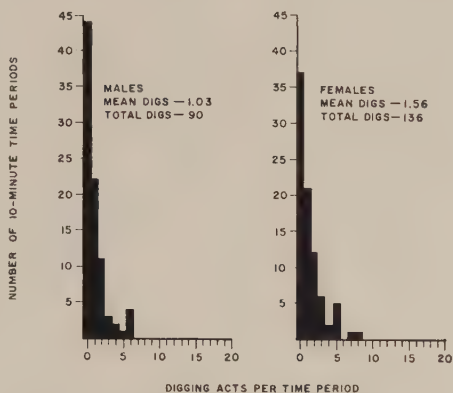


Fig. 5. Reddigging by spawning sockeye salmon during 87 10-minute periods.

as many as 4 spawning waves for South Sakhalin pink salmon. It may be that even with wave spawning, excavation of isolated egg pockets is not a serious loss. Further research is scheduled for this critical period in salmon life history.

In Brooks River, male spawners die earlier on the average than females. This is also true of other systems (Krogus and Krokhn 1956, and Killick 1955). Perhaps the males' greater defensive activities cause earlier exhaustion. Whatever the reason, this differential life-span must be recognized when escapement surveys are made to estimate spawning population sex ratios. In Brooks River males die and the carcasses appear 4 days before females. The sex ratio of newly dead fish shifts in several days to females until all fish in that spawning wave are dead. Then, males from the second spawning wave start dying and dominate the samples. Sex ratio estimates for escapements based on spawning ground surveys should therefore be made on counts of both live and dead fish or on counts of dead fish after all spawners have died.

The final discussion concerns the wide range in redd densities observed at Brooks River and Karluk Lake and reported in the literature. Obviously, redd densities can change between years in the same spawning area because of different numbers of spawning females. It does appear, however, that different types of spawning areas support different redd density maxima. The minimum average size of redd territories in Brooks River is probably not less than 50

ft². In many areas in the small streams lateral to Karluk Lake, the minimum average size may be less than 9 ft². What factors are related to this differential redd density?

Karluk Lake lateral spawning streams are shallow (6 to 12 in. deep) and are strewn with large stones and boulders. In many streams redd sites 3 ft apart are completely separated by boulders. Spawners over one such redd are not apparently intimidated as frequently by spawners over adjacent partially observed redds as they would be in the open waters of larger streams or lake beaches. Spawning area topography thus seems to play an extremely important role in redd density. Fabricius (1951) pointed out that this also holds true for White Cloud Mountain fish (*Tanichthys albonubes*) and bream (*Abramis brama*). Bream territories observed along an open lake shore "were as a rule considerably larger than the territories in the thicker reed." As Fabricius noted, the study of redd density is of great practical importance, for redd density has at least an indirect effect on the quantity of eggs that can be deposited in a spawning area.

The factors influencing the size of redd territories, other than fish density, should be investigated. Findings may help us understand the wide differences in redd density occurring in different habitats and also may point toward ways of physically modifying certain existing spawning areas and newly constructed artificial spawning areas to increase their capacities for redds.

ACKNOWLEDGMENTS

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PHOTOTACTIC BEHAVIOUR OF EMERGING SOCKEYE SALMON FRY

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When sockeye salmon fry (*Oncorhynchus nerka*) leave their natal gravels, they usually migrate downstream into a lake, where they encounter conditions quite different from those of the gravels. Knowledge of behaviour during this critical transitional period is important in understanding survival during the early life history of the species. Although much has been written on the behaviour of salmonid fry during their downstream migration, little is known of their behaviour as they first emerge from the gravel.

This paper describes the emerging patterns of sockeye salmon fry in Brooks River, Alaska, during periods of normal daylight and darkness and periods when the nursery gravels were exposed to continuous illumination by artificial means.

In various studies in troughs and aquaria, Hoar (1954) showed that sockeye salmon fry exhibit "a preference for low light intensities". Under field conditions, Neave (1955) found that pink salmon fry (*O. gorbuscha*) and chum salmon fry (*O. keta*) migrate principally at night. McDonald (1960) recorded similar behaviour patterns for sockeye and coho salmon (*O. kisutch*). McDonald (1960) and Hartman, Strickland and Hoopes (1962) reported a seasonal reduction in the hours of nightly migrations of sockeye salmon fry corresponding to a progressive shortening of periods of darkness. These workers, Neave (1955) and Hoar (1956) showed that pink, chum and sockeye salmon fry usually migrate as individuals and are negatively rheotactic as well as phototactic, and that these initial responses eventually give way to rapid, dramatic changes in behaviour. After emergence, exposure to bright light and, usually, the completion of downstream migration, these fry formed schools and became neutrally or positively orientated with reference to light and current.

The purposes of my study were to:

1. Determine if sockeye fry emergence could be influenced by continuous light obtained by exposing nursery gravels to artificial light at night.

2. Determine the diel periodicity (the 24-hour period of a day and a night (Northcote, 1962)) of the emergence of fry.

3. Determine the duration of fry emergence from small segments of a spawning area.

The study was conducted during the spring of 1961 at Brooks River on the Alaska Peninsula. The river is 1.3 miles long and connects Brooks Lake to Naknek Lake. The study area, located one-half mile below the outlet, was 200 feet long, 100 feet wide, and 20 inches deep. Streamflows averaged about 500 c.f.s. during the autumn spawning period and about 300 c.f.s. during the spring.

Material and Methods

Six emergent fry traps were constructed, each covering 8 square feet of gravel (Fig. 1). A vertical wooden partition divided the traps in half so that one of the sides could be artificially lighted without affecting light conditions on the opposite side. The partition extended approximately 6 inches into the gravel, preventing intragravel movement of fry near the gravel surface between the two sides. A small-mesh nylon bag was attached to a funnel-type throat at the downstream end of each side.

A portable petrol 110-volt a.c. power plant was used to provide power to a 40-watt fluorescent light fixture on one side of each trap. A reflector over each fixture increased illumination and confined light to the desired half of the trap. Standard Warm White fluorescent bulbs were used. The lighted half of each trap was designated "Side B" and the other half "Side A". Side B was on the left in four traps and on the right in two.

During September and October of 1960, the locations of sockeye salmon redds in the study area were recorded. Fry began to emerge early in May 1961, and the first trap was set on May 12th. Care was taken not to disturb the gravel over which the traps were set. McAfee found the average Brooks River redd, in 1959, to be approximately 22 square feet, and because sockeye salmon characteristically deposit their eggs in pockets, which results in a patchy distribution throughout the redd (McAfee,

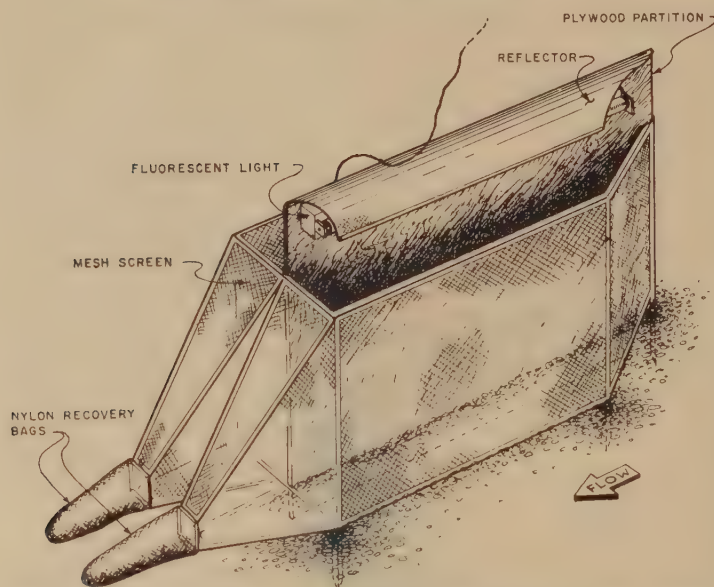


Fig. 1. Traps used for sampling emergent fry, Brooks River, 1961. Partition and trap legs are buried approximately 6 inches in the gravel.

1960), some traps had to be tested at several points within a redd until fry were being caught in both sides. The period of adjustment extended from May 12th to 22nd, and experimental lighting was initiated on May 24th. Lights over Side B of all traps were turned on for an uninterrupted series of nights. They were then kept off for a series of nights and turned on again for another experimental period. Nocturnal and daylight emergence from Side A and Side B of each trap was recorded for each period. Once this procedure was begun, all traps remained in the same location.

The lights were turned on in the evening just before natural illumination dropped below 30 foot-candles and were turned off the following morning as soon as natural illumination rose above 30 foot-candles. At that time both sides of each trap were checked for nocturnal emergence. Daylight emergence was checked each evening when natural illumination dropped to 30 foot-candles. Debris was cleaned from the traps daily with a wire brush.

Artificial light intensities, which were measured at the water surface directly under the fluorescent lamp with a model 200-C photovolt meter, were relatively constant for the same trap on different nights. The illumination varied

from trap to trap, depending on the distance from the lamp to the water surface. The average illumination at 0030 hours on May 28th was approximately 33 foot-candles (Table I).

Light intensity at the water surface in Side B of each trap averaged 30 foot-candles, more for the duration of the experimental series. This was assumed to be enough illumination to influence normal nocturnal behaviour patterns of salmon fry. McDonald (1959) noted that the nocturnal behaviour patterns of sockeye salmon fry did not become evident until illumination fell below 0.1 foot-candle.

The exact relationship between light intensity measured at the water surface in the trap and the amount of light reaching the gravel and penetrating into it is not known. A series

Table I. Light Intensities Measured at Water Surface in Emergent Fry Traps at 0030 hours, Brooks River, May 28th, 1961.

Trap	Illumination (foot candles)		Distance from lamp to water surface (inches)
	Side A	Side B	
1	0	40.8	13
2	0	29.5	19
3	0	30.9	16
4	0	31.2	14
5	0	28.9	19
6	0	37.5	14

light measurements taken in Brooks River on June 14th at 2100 hours (Table II) shows differences in light intensity at the water surface, at the gravel surface and at two depths within the gravel.

Artificial lights were used from the nights of May 24th through 30th, June 4th through 11th and June 21st through 23rd. The last emergent fry was caught the night of July 4th. Since only six fry were caught in all traps after the night

II. Differences in Surface and Sub-surface Light Intensities Measured at 2100 hours, Brooks River, June 14th, 1961.

Position of photoreceptor	Illumination (foot-candles)
Water surface	55.0
Beneath 17 inches of water at surface of Gravel*	30.5
Buried 1 inch beneath 0.5-inch gravel	3.0
Buried 2.5 inches beneath 0.5-inch gravel	0

Turbidity of the water measured 8.3 p.p.m. SiO₂.

On June 29th, phototactic studies were terminated at that date. All traps were left in place, however, in order to determine the last date of emergence.

Results

Between May 22nd and June 29th, 6,132 fry were caught in the six emergent traps. Although the 39 days did not cover the entire period of emergence from Brooks River gravels, early season fyke net catches of fry migrants suggest that at least 90 per cent. of the emergence occurred in this period. No fry were actually observed emerging from the gravel, but it seems reasonable to equate catches in the traps with emergence insofar as phototactic responses and timing of emergence are concerned.

The seasonal pattern, as indicated by the number of emergent fry caught daily is shown in Fig. 2. This pattern may not be completely normal because fry emerging from one side of each trap were periodically subjected to natural periods of continuous light.

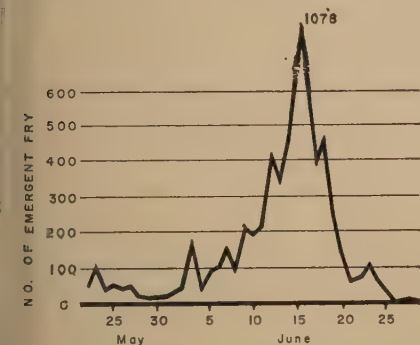


Fig. 2. Daily numbers of emergent sockeye salmon fry caught in six traps.

The number of fry caught in individual traps varied considerably—from 588 to 1,882—but the combined total emerging from Side A compared with the total emerging from Side B was similar—3,134 from Side A and 2,998 from Side B (Table III). The difference of 136 is not significant (chi square=3.0, d.f. 1). The nocturnal-daylight patterns of emergence between the two sides differed markedly, however.

Table III. Numbers of Emergent Sockeye Salmon Fry Caught in Sides A and B of Six Emergent Fry Traps, Brooks River, May 22nd-June 29th, 1961.

Trap	Number of fry		
	Side A	Side B	Total
1	350	598	948
2	334	440	774
3	370	458	828
4	696	416	1112
5	1033	849	1882
6	351	237	588
Total	3134	2998	6132

Nocturnal Emergence

Of the total number of emergent fry trapped in Side B, approximately 80 per cent. were caught at night. During the 39 nocturnal periods in the study, natural darkness was allowed over Side B of each trap for 18 nights, and artificial light was produced over Side B for 21 nights. Natural darkness was allowed over Side A for all 39 nights. The combined totals of all nocturnal emergence occurring in Side B (Table IV)

Table IV. Night and Day Emerging Fry Caught in Sides A and B of Six Traps during Normal and Experimental Periods.

Period	Side A		Side B		Total
	Night	Day	Night	Day	
During 18 normal diel periods	1206	208	1729	149	3292
During 21 diel period when Side B was exposed to experimental light at night	1429	291	659	461	2840
Total	2635	499	2388	610	6132

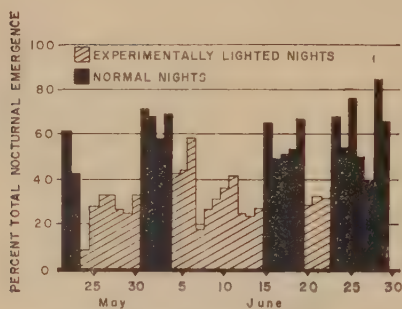


Fig. 3. Percentage of total nocturnal emergence occurring in Side B of six traps.

reveal that during experimentally lighted nights, only 28 per cent. (659 fry) of the emergence occurred, while during normal night 78 per cent. (1,729 fry) occurred.

To understand fully the relationship between nocturnal emergence in Side B and normal and experimentally lighted nights, it is necessary to consider the total combined nocturnal emergence from both sides of all traps that occurred on each night. When the percentage of the total nightly emergence that occurred in Side B is plotted for each of the 39 nocturnal periods, Side B catches show low and high proportions throughout the study that correspond with experimental and normal nights respectively (Fig. 3).

Nocturnal emergence in Side A was more evenly divided between normal and experimental periods. During the 18 normal nights, representing 46 per cent. of the nocturnal periods, 46 per cent. of the nocturnal emergence from Side A occurred. During the 21 experimental nights, 54 per cent. of the nocturnal emergence from Side A occurred.

Daylight Emergence

Of all emergent fry trapped, 18 per cent. (1,109) were trapped during daylight hours (Table IV). Daylight emergence accounted for 16 per cent. of the total catch in Side A and 20 per cent. in Side B. Daylight emergence was greater in both sides of the traps during experimentally lighted periods than during normal periods. Daylight emergence comprised 17 and 15 per cent. of the emergence in Side A during the experimental and the normal periods, respectively. Fry emerging during daylight in Side B accounted for only 8 per cent. of the

emergence in that side during unlighted periods. During experimentally lighted periods, however, daylight emergence represented 41 per cent. of the fry caught in Side B. By computing the percentage of emergence in Side B for each of the 39 periods and then plotting the per cent. emergence that occurred during daylight hours (Fig. 4) it can be seen that daylight emergence in Side B was greatly accelerated on days after experimental light at night. The combined totals of

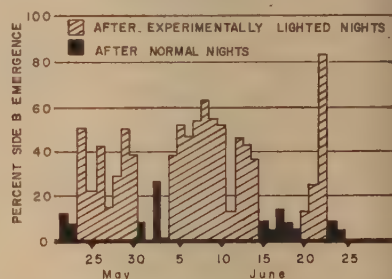


Fig. 4. Percentage of emergence in Side B of six traps occurring in daylight periods.

fry caught in Side B by night or day and normal or experimental diel period (Table IV) show that fry emergence in Side B decreased at night and increased during the day when gravel was exposed to continuous light.

Active downstream migration may not immediately follow emergence from the gravel, particularly during daylight hours. Hoar (1953) suggested that a reduction in visual fixation with reference to the gravel environment may provide the mechanism of downstream migration. Fry that do emerge during daylight could maintain orientation with the gravel. Such fry might remain out of the gravel or hide briefly before re-entering the gravel or hiding in available cover. Stuart (1953) gives laboratory examples of behaviour analogous to this in young brown trout (*Salmo trutta*). Neave (1953) discusses daylight cover-seeking in streams recently emerged pink and chum salmon. and Hartman *et al.* (1962) describe daylight holding areas of sockeye salmon fry in a stream.

Approximately 150 feet below the origin of the Brooks River, fyke nets, used annually to sample sockeye salmon smolt emigrations from Brooks Lake, also sample fry that are spawned between the lake and the fyke net trapping sites. The nets are fished mostly at night. Periodical

are fished around the clock to check day-fish movements. During eleven such 24-hour checks in 1961, 11 per cent. of the fry caught were taken during daylight periods. Although this daylight fry activity was less than observed in the emergent traps, it is probably significant that both the fyke nets and emergent traps were located on and immediately adjacent to gravels from which fry were emergent. Migrant salmon fry trapping is normally conducted at the downstream terminus of a spawning area (McDonald, 1960; and Hartman *et al.*, 1962), where activity of emerging fry exhibit only a short net downstream movement would go undetected.

Duration of Emergence

Downstream migration of sockeye salmon from a spawning stream may last for 6 or 7 weeks (McDonald, 1960, and Hartman *et al.*, 1962). The migration period for a specific spawning area is probably determined by the timing of the spawning runs and the environmental conditions of nursery gravels during the growth and development of eggs and alevins. In my study, the duration of emergence was determined from small segments of a spawning area. Since some fry probably had emerged from the gravels before the traps were in place, the data may represent minimal periods of emergence.

The greatest time interval between initial and final observed emergence of fry from a 4-square-foot area (half of one trap) was 48 days, while the shortest time was 37 days. The average for all areas was 41 days (Table V). The emergence periods of Sides A and B of the traps indicate that experimental lighting did not affect the duration of emergence. In a controlled, experimental, gravel-filled trough, coho salmon fry (*O. kisutch*) required 43 days from initial to final emergence (Shapovalov & Berrian, 1940). Similarly, Hanavan (1954) found the period of emergence for pink salmon fry (*O. gorbuscha*), spawned in pens 8 feet $\times$ 4 feet, to be more than 45 days.

No trap was known to cover only one redd, although it is unlikely that multiple spawnings by different pairs of fish occurred in each of the 2 separate 4-square-foot areas. This suggests considerable variation in timing of emergence of fry produced from a single redd. Such variability together with the variation in timing of emergence between redds may provide inherent survival advantages by assuring that some fry

Table V. Known Duration of Sockeye Salmon Fry Emergence from Twelve 4-Square-Foot Areas of Gravel, Brooks River, 1961.

Trap	Side	Date first emergent fry caught	Date last emergent fry caught	Minimum period of known emergence from each 4-square-foot area (days)
1	A	May 13	June 30	48
1	B	May 13	June 25	43
2	A	May 21	July 2	42
2	B	May 21	July 4	44
3	A	May 16	June 25	40
3	B	May 14	June 29	46
4	A	May 22	July 1	40
4	B	May 23	July 1	39
5	A	May 21	June 28	38
5	B	May 21	June 30	40
6	A	May 21	June 28	38
6	B	May 21	June 27	37
Mean				41

will encounter better survival conditions upon entering the nursery area.

Discussion

Most of the emergent fry trapped during this study had little or no yolk remaining and had essentially passed through the alevin stage. Because these fish had developed from fertilized eggs to alevins to emergent fry in the darkness of natal gravels, it was assumed that darkness or lack of it influenced their movement from the gravel. Eisler (1957) showed that normal development of salmon eggs can occur in a lighted environment, although survival was directly proportional to light intensity. The adverse effects of specific wave-lengths of light on salmonid eggs and larvae have been discussed by Bell & Hoar (1950) and Perlmutter & White (1962).

Woodhead (1957) demonstrated a photokinesis for alevins of brown trout. Both Woodhead (1957) and Stuart (1953) pointed out that such a behaviour, when alevins were negatively phototactic, would tend to confine fish within the gravel. Under natural conditions,

emergence in the strictest sense begins with the first vertical movement of the alevin toward the gravel surface. This initial movement is not influenced by light intensity but most likely by physiological changes within the fish, or it may be a behaviour response to some other stimulus in the gravel environment. Apparently, it is only after a fish has moved into a narrow stratum just beneath the gravel surface that light has an opportunity to influence its behaviour (Table II).

Little is known about intra-gravel movements of salmonid alevins or at what stage they begin their ascent toward the gravel surface. Shapovalov (1937) indicated that steelhead trout fry (*Salmo gairdneri*) start emerging from the gravel 2 or 3 weeks after the eggs hatch. Stuart (1953) found that brown trout alevins initially moved horizontally in the gravel, then outward and upward, which made the general distribution of fry in the gravel somewhat cone-shaped, with the apex toward the point of origin. Woodhead (1957) pointed out that brown trout may emerge with considerable yolk remaining. Behaviour patterns for salmonids with or without yolk at the time of emergence may be quite different.

It seems likely that the emergence of sockeye salmon fry from nursery gravels marks the beginning of the changes in behaviour associated with downstream fry migrations and initial nursery lake residence. These changes may also be related to final yolk absorption and, as Neave (1955) suggested, the necessity to begin feeding. McDonald (1960) found that pink salmon fry in long rivers began feeding before completing their migration.

In laboratory experiments, Stuart (1953) found changes in brown trout behaviour during the period of final yolk absorption that correspond with changes in sockeye salmon fry behaviour during emergence, downstream migration, and initial lake life. Brown trout alevins were negatively phototactic and rheotactic until yolk absorption was complete, at which time their responses to these stimuli became neutral or positive (Stuart, 1953).

An indication of the initial breakdown of negative phototaxis is suggested in Side A catches, where 16 per cent. of the fry emergence occurred during normal daylight that was not preceded by experimentally lighted nights. Hartman *et al.* (1962) found that only 2.1 per cent. of the sockeye salmon fry migrated from Hidden Creek during daylight hours, and McDonald (1960) reported no daylight migration from Williams Creek. The extent of daylight emerg-

ence observed in my study suggests that sockeye salmon fry are less reluctant to emerge from the gravel than to migrate downstream during daylight.

If sockeye salmon alevins remain in the light penetrable zone of gravel for any length of time before final emergence, they become exposed to the normal day-night cycle. If, on the other hand, movement into and through this upper zone of gravel occurs only during final emergence, fry may leave the gravel without having been exposed to this cycle. Regardless of the sequence, emergent behaviour toward light is essentially negative, and most fry leave the gravel in darkness.

The strength of this negative phototactic behaviour was great enough to reduce nocturnal emergence at the beginning of each period of experimentally produced continuous light (Fig. 3). This behaviour in some cases apparently was altered, as evidenced by the sharp increase in daylight emergence from gravels exposed to light (Fig. 4). A physiological readiness to leave the gravel in these cases may have superseded the negative phototactic behaviour response.

Although a reduction in nocturnal emergence was countered by an increase in daylight emergence almost to the point where emergence during the two periods was equal, the total number of fry emerging was less than what it would have been without the experimental stimulus of continuous light. A strong resurgence of nocturnal emergence in Side B of the traps occurred on the first night of normal darkness after experimentally lighted nights (Fig. 3). Although the total numbers of fry emerging from Sides A and B were essentially the same, the total emergence from Side B during experimentally lighted periods was only 65 per cent. of that of Side A. The total emergence from Side B during normal periods (Table IV) was 133 per cent. of that from Side A. It is assumed this difference was the result of a general retardation of emergence from gravels in Side B during periods of continuous light.

It appears that daylight emergence may exceed daylight downstream fry migration. The daylight cover-seeking and holding behaviour of newly emerged fry (Neave, 1955, and Hartman *et al.*, 1962) reasonably explains why most downstream fry migration occurs nocturnally. It should be noted, however, that in turbid streams, substantial daylight migrations of pink and chum salmon fry have been recorded by Neave (1955); and McDonald (1960) found that

proportion of pink salmon fry migrating during daylight increased with an increase in length of the spawning stream.

Summary

A fry trap designed to study the behaviour of emerging sockeye salmon fry in Brooks River, Alaska, during the spring of 1961 revealed the following:

1. The initial emergence of sockeye salmon from natal gravels was basically nocturnal. Evidence is presented that suggests initial daylight emergence may exceed daylight downstream migration of fry.

2. The minimum duration of sockeye salmon emergence from twelve 4-square-foot gravel areas ranged from 37 to 48 days and averaged 42 days.

3. Nocturnal emergence was retarded and daylight emergence was accelerated when nursery gravels were exposed to artificial light at night. The over-all rate of emergence was retarded during periods of continuous light. This decrease was followed by a strong resurgence of nocturnal emergence on the first night of normal darkness after the experimentally lighted nights.

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Abundance, Age Composition of Landings, and Total Mortality of Haddock Caught Off Southern Nova Scotia, 1956-1961

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Abstract

Haddock stocks in Division 4X of the Convention Area for the International Commission for the Northwest Atlantic Fisheries (ICNAF) have been exploited for many years by Canada and the United States. The present study covers the period 1956-1961 and represents the first comprehensive analysis of this fishery. General characteristics of the fishery are described, and estimates of abundance, growth, year class strength, and total mortality are presented.

About 70 percent of the 1956-61 landings (91,161 metric tons) were accounted for by otter trawls and the remainder by hook and line gear. Nearly three-fourths of the landings came from waters off southern Nova Scotia (chiefly Browns Bank) and the remainder from the Bay of Fundy.

Average annual survival rate of Division 4X stocks was approximately 0.50 corresponding to an instantaneous total mortality rate of 0.7. However, Bay of Fundy haddock exhibit faster growth and a younger age composition than those from waters off southern Nova Scotia. Age composition of Bay of Fundy stocks is similar to that of Division 5Z (Georges Bank), but growth is faster in the latter area. Both growth and age composition of haddock off southern Nova Scotia is similar to that for stocks off central Nova Scotia, (Divisions 4V-W).

Certain year classes appeared strong in all Divisions (5Z to 4W) suggesting that factors common to the entire area may control brood success, or that stocks mix at some pre-recruit stage.

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Introduction

The fishing area under study is delineated by the boundaries of Division 4X of the Convention Area for the International Commission for the Northwest Atlantic Fisheries (ICNAF) (Fig. 1). The relationship of the stocks within these boundaries to those to the north and south



Fig. 1. Geographical divisions of the International Commission for the Northwest Atlantic Fisheries (upper panel), and sampling areas and subareas (lettered) of Division 4X employed in this study (lower panel).

is not yet clearly defined, although there is some evidence of autonomy (Clark and Vladykov, 1960). Regardless of racial structure, neither the stocks of haddock nor the fishery is continuously distributed throughout its western Atlantic range. Division 4X encompasses one geographical segment where the fishery and the fish tend to be concentrated, forming a convenient unit area for study.

The stocks within this area have been exploited for many decades by Canadian and American fishermen. During the years under study, 1956 to 1961, the total landings have fluctuated between 28 and 40 million pounds (13 and 18 thousand metric tons)³ annually. Landings are summarized in Table 1 and Fig. 2 by quarter⁴, type of gear, and sampling areas.

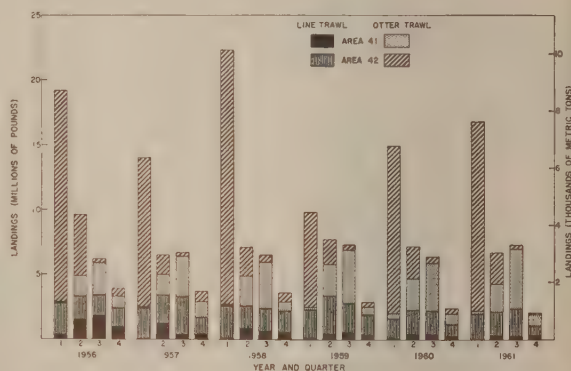


Fig. 2. Landings of haddock caught in Division 4X by type of gear, sampling area and quarter.

Landings by hook and line gear, exclusively Canadian, accounted for 29 per cent of the total during the period, and gradually declined from 10.7 million pounds (4.8 thousand metric tons) in 1956 to 7.7 million pounds (3.5 thousand metric tons) in 1961. Vessels using line gear fished mostly in Sampling Area 42, and their landings were fairly uniform throughout the year. Otter trawlers, predominantly U.S., have landed between 17 and 30 million pounds (8 and 14 thousand metric tons) annually. The catch by otter trawlers in Sampling Area 42 averaged 17 million

³) All weights in this paper refer to dressed weights; haddock are gutted and stored in ice for periods up to two weeks before landing. Approximate estimates of round, fresh weights may be obtained by multiplying the as-landed weights by 1.17.

⁴) These are not calendar quarters. The first quarterly period commences with February, and the fourth quarter of a given year terminates with January of the following year. These periods were chosen by earlier investigators to center the peak of spawning within a time stratum, the first quarter. This choice is somewhat arbitrary, and we have used the system for sake of conformity.

TABLE 1. Landings in thousands of pounds of haddock caught in Division 4X by quarter, sampling area, and type of gear, 1956-61. Totals shown in parentheses are in metric tons.

Year	Qtr.	Hook and Line - Canada			Otter Trawl - U.S. and Canada			Grand Totals
		Sampling Area		Totals	Sampling Area		Totals	
		41	42		41	42		
1956	1	303	2494	2797	81	16348	16429	19226
	2	1522	1746	3268	1590	4770	6360	9628
	3	1775	1641	3416	2464	287	2751	6167
	4	901	1473	2374	900	636	1536	3910
Totals		4501 (2042)	7354 (3336)	11855 (5377)	5035 (2284)	22041 (9998)	27076 (12282)	38931 (17659)
1957	1	17	2441	2458	78	11506	11584	14042
	2	1244	2113	3357	1624	1485	3109	6466
	3	357	2940	3297	3056	329	3385	6682
	4	360	1337	1697	1178	832	2010	3707
Totals		1978 (897)	8831 (4006)	10809 (4903)	5936 (2693)	14152 (6419)	20088 (9112)	30997 (14015)
1958	1	99	2466	2565	144	19629	19773	22338
	2	804	1789	2593	2343	2206	4549	7142
	3	633	1746	2379	3595	528	4123	6502
	4	545	1705	2250	662	676	1338	3588
Totals		2081 (944)	7706 (3495)	9787 (4439)	6744 (3059)	23039 (10450)	29783 (13509)	39570 (17949)
1959	1	55	2266	2321	222	7243	7465	9786
	2	453	2972	3425	2350	1905	4255	7680
	3	479	2354	2833	4088	412	4500	7333
	4	337	1545	1882	661	364	1025	2907
Totals		1324 (600)	9137 (4145)	10461 (4745)	7321 (3321)	9924 (4501)	17245 (7822)	27706 (12567)
1960	1	30	1591	1621	339	12915	13254	14875
	2	352	1992	2344	2316	2590	4906	7250
	3	352	1845	2197	3672	516	4188	6385
	4	211	1048	1259	771	371	1142	2401
Totals		945 (429)	6476 (2937)	7421 (3366)	7098 (3220)	16392 (7435)	23490 (10655)	30911 (14021)
1961	1	1	2064	2065	181	14509	14690	16755
	2	277	1875	2152	2142	2451	4593	6745
	3	259	2160	2419	4572	317	4889	7308
	4	310	795	1105	851	193	1044	2149
Totals		847 (384)	6894 (3127)	7741 (3511)	7746 (3513)	17470 (7924)	25216 (11437)	32957 (14949)
Grand Totals		11676 (5296)	46398 (21046)	58074 (26342)	39880 (18089)	103018 (46729)	142898 (64819)	200972 (91161)

pounds per year (8 thousand metric tons), which was over twice that in Sampling Area 41. About 80 percent of the otter-trawl landings from Sampling Area 42 was taken in the first quarter, whereas about 80 percent of the otter-trawl landings in Sampling Area 41 was taken in the second and third quarters.

Biologists of the U.S. Bureau of Commercial Fisheries Biological Laboratory, Woods Hole, and the Fisheries Research Board of Canada, Biological Station at St. Andrews, initiated a co-operative study of this fishery in 1956. Although investigations had been conducted previously by each country, the studies had not been

comprehensive, and had not adequately considered the joint nature of the fishery. The landings of vessels of the two countries were nearly equal from 1956-61, but there was a differential distribution of fishing effort among gear, seasons, and areas. Emphasis was placed on the collection of statistics of landings and effort, and of samples of length and age frequencies of the landings.

This paper presents the results of analysis of these data. Estimates of average length and weight at age, abundance of year classes, and total mortality have been obtained. Comparisons of these statistics have been made among areas and quarters to elucidate interrelationships of the stocks.

Most of the otter trawls are fitted with a cod end of 4½ inch, manila mesh or its equivalent in synthetic material, as stipulated by ICNAF regulations. The sizes of fish retained by this mesh size are generally acceptable on the market, and there is little discard. Discarding of fish caught by line gear is also negligible. The landings are nearly equivalent, therefore, to the catch with respect to length of fish and amount. Neither the catch nor landings truly represent the population, of course, but we do assume the changes observed in landings and samples therefrom reflect changes in the population beyond the age of full recruitment.

Methods of Sampling, Ageing and Analysis

1. Sampling methods

For purposes of sampling and recording fishery statistics, Division 4X was originally divided into seven small subareas, lettered M through S (Fig. 1). Off Southern Nova Scotia, the offshore fishing grounds are contained within N and P, and the inshore grounds within M, O, and Q. R and S represent the Bay of Fundy fishing grounds. Samples were taken from landings of fish caught entirely within one of the subareas, and the day of landing determined the month to which a sample or landing was assigned. For purposes of analysis, the data were subsequently grouped into two larger sampling areas: Sampling Area 42, which includes Subareas M through Q, the Southern Nova Scotia grounds; and Sampling Area 41, which includes Subareas R and S, the Bay of Fundy grounds.

United States and Canadian haddock catches are landed in three market categories: scrod (1.5 to 2.5 pounds; 0.7 to 1.1 kg), large (over 2.5

pounds), and ungraded (over 1.5 pounds). A 2.5 pound haddock is about 50 cm in length. Fish are unloaded from vessels typically into boxes or carts, and length measurements and otoliths are taken from haddock selected from containers of each market category. The sample is best described as a "grab" sample, i.e., fish are taken from the container in a blind fashion, topmost layer first, until the requisite number has been obtained.

Virtually all haddock caught by U.S. otter trawlers are culled at sea and landed as large or scrod. A minimum of 100 large haddock and 50 scrod haddock are measured for each sample, and usually both large and scrod are obtained from each trip sampled. Otoliths are taken from 20 large and 15 scrod selected, insofar as possible, so that the entire range of lengths encountered is uniformly represented.

Canadian fishermen employ otter trawls, and hook and line (longlines and handlines) gear. Haddock are landed in all three market categories. The large and scrod categories are similar in size of fish to the corresponding U.S. categories. The ungraded category is from catches which have not been culled at sea. During the period of study usually 200 or more lengths were obtained from a single landing⁶. If both large and scrod were sampled from a single landing, the scrod sample was limited to about 15 percent of the total sample. Usually not less than 40 otoliths and often more than 100 were collected from a single landing, but for the samples of more than 50 otoliths, a stratified (by length) subsample of 50 was drawn for reading. Haddock were sampled representatively for both length frequency measurements and otoliths.

2. Age assessment

All ages are based on otolith readings by Norman McFarlane, St. Andrews, and John P. McDermott, Woods Hole. Criteria for identifying year marks on haddock otoliths in Nova Scotian waters were established by Kohler (1958), who guided the training of the two readers.

Otoliths from 736 fish were read independently by each of the two readers, and they disagreed on 143 (20 percent). Among the 143 discrepancies, 114 (80 percent) involved a difference of only one year and 22 a difference of two years. McFarlane's readings, however, were lower than McDermott's in 70 percent of the 143 discrepancies. The tendency for McFarlane to get

⁶In Canada, catches of small vessels are frequently combined at time of unloading, in which case a single sample would represent the catch of several vessels.

TABLE 2. Comparison of 736 haddock otoliths read independently by each of two readers. Readings in agreement are in **bold** figures.

	Aged by McFarlane															Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+	
Aged by McDermott																
1	14															14
2		68	2													70
3		6	129	6												141
4		3	10	116	13											142
5			1	6	102	7										116
6				3	14	58	3									78
7					1	7	50	4								62
8					1	4	10	19	5		1					40
9							2	9	20		1					32
10								4	4	7	1					16
11								1	2	6	4	1				14
12										1		4				5
13										1			1			2
14										1	1					2
15+													1		1	2
Total	14	77	142	131	131	76	65	37	31	16	8	5	2		1	736

lower ages appears to begin about age 6 and is present thereafter (Table 2). Simultaneous examination of otoliths by these two readers showed that discrepancies were due primarily to differences in interpreting weak marks, which occurred on some otoliths, either as annuli or as checks.

An approximate measure of the effect of discrepancies of this magnitude on estimates of mortality was obtained by converting Table 2 into a hypothetical set of percentage errors in age readings. This was done by assuming that the readings of one reader were correct and then converting discrepancies with the other reader into percentages. The "percentage errors" were then applied to a percentage age frequency corresponding to the average percentage age distribution of the first quarter of otter-trawl landings in Sampling Area 42. Survival estimates were computed from both the original and the adjusted age frequencies using a simple estimator described by Robson and Chapman (1961). Differences in survival estimates between ages 6 and 11 were less than 5 percent, and the difference in average age landed was less than 0.2 of one year. Consequently the results based on age data in this report are essentially the same as if only one reader had been used.

Winter growth zones of haddock are noticeable on otoliths beginning in the third quarter of the year and are consistently distinguishable by 1 February. The birthday was taken as

1 February, that is, otoliths showing n winter growth zones in the third and fourth quarter were assigned an age $n-1$, but commencing in the first quarter an age n was assigned.

3. Methods of analysis

Let n_{ijk} be the pooled sample length frequencies for the i th 2-cm length interval, j th month and k th market category within each type of gear, sampling area, and quarter. The estimated quarterly number of fish landed per 2-cm length interval is,

$$N_i = \sum_{jk} (n_{ijk} W_{jk} / \sum_i n_{ijk} w_{ij}),$$

where W_{jk} is the weight landed, and w_{ij} is the mean weight at length taken from data of Clark and Dietsch (1959).

Whenever a particular set of n_{ijk} was missing from the data, the average length frequency of the other months or market categories within the quarter was used to supply estimates of the N_{ijk} , which were added to the quarterly totals. The N_i were not estimated if there was not at least one length frequency sample for each of the market categories within the quarter, or if the numbers of fish measured were too small to provide a reliable frequency (here, the minimum number was set arbitrarily at about 100). Some exceptions to

this rule were made for strata where length samples from ungraded landings were used to prorate all landings including large and scrod, or vice versa. These instances are mentioned under the appropriate section, and suitable comparisons made where necessary to validate the procedure.

Having thus obtained the quarterly N_i , the sample age-frequencies were pooled within each quarter by 2-cm intervals, to obtain an age-length key. The N_i were multiplied by the percentage age-at-length frequencies and summed within each age group to obtain the numbers of fish landed at each age. Mean length and weight per fish of each age group then were computed, again using data on mean weight at length given by Clark and Dietsch (1959).

In most quarters, the sum of the estimated numbers landed in each age group was 1 or 2 percent less than the total numbers landed as estimated from the length-frequency data. This difference occurs because otoliths from fish in the larger and smaller length intervals were not always obtained in the samples. Age groups 2, 3, 11, and 12 are affected, primarily. Therefore, the numbers of fish landed are underestimated for all these age groups, and the mean length and weight are overestimated for the younger age groups, and underestimated for the older. We shall point out in subsequent sections the results which are affected by this bias.

In addition, the lesser numbers of otoliths sampled from larger and smaller fish increases the variability of the corresponding estimates, but the above points up an inaccuracy rather than imprecision.

TABLE 3. Landings (guttled weights, lb. $\times 10^{-3}$) of haddock and numbers of fish measured and aged for otter-trawl landings, Division 4X, Sampling Area 42.

Year	Qtr.	Landings			Measured	Aged
		U.S.	Can.	Total		
1956	1	15754	594	16348	3782	218
	2	4549	221	4770	906	—
	3	84	203	287	668	—
	4	453	183	636	345	—
1957	1	10687	818	11505	2984	381
	2	1320	165	1485	160	34
	3	162	166	329	222	—
	4	740	92	832	56	15
1958	1	18116	1513	19629	2903	305
	2	2067	138	2205	204	—
	3	279	249	528	159	—
	4	566	110	676	121	15
1959	1	6856	388	7243	1830	383
	2	1736	169	1905	1396	243
	3	346	66	412	82	61
	4	344	20	364	110	—
1960	1	12559	356	12915	2561	610
	2	2197	393	2590	855	143
	3	233	282	516	125	75
	4	248	123	371	—	—
1961	1	14452	56	14509	3502	704
	2	2264	187	2451	471	75
	3	284	34	317	319	34
	4	151	42	193	—	—

Sampling Area 42 (Southern Nova Scotia)

1. Otter-trawl fishery

Quarterly otter-trawl landings by country, and numbers of fish measured and aged in samples of the landings are presented in Table 3. The bulk of the landings (76 percent for the 1956-1961 period) were accounted for by the United States fleet in the first quarter. The United States vessels fished principally on Browns Bank.

Adequate estimates of length and age composition of landings were obtained only for U.S. landings in the first quarter of each year, and in the second quarter of 1959 and 1960. Canadian landings, therefore, had to be prorated by the length and age composition of the United States landings to provide the total biostatistics for these quarters.

Comparison of length samples collected from otter trawl landings of both countries in March of 1956 and 1958, and in April 1957 indicate that Canadian landings have a somewhat higher proportion of smaller-sized fish within both market categories (Fig. 3).

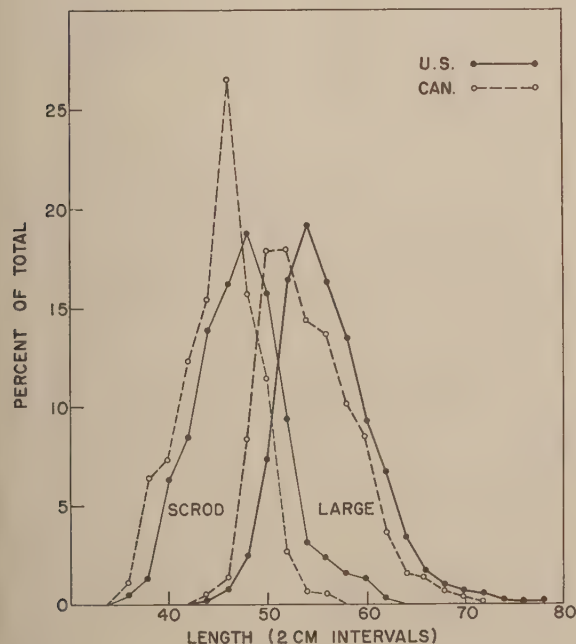


Fig. 3. Comparison of length-frequencies of samples from U.S. and Canadian landings of otter trawlers fishing in Sampling Area 42.

However, the bias introduced in the estimates is negligible because of the relatively small amounts landed by Canadian otter trawlers in the first quarter.

1.1 Average length and weight at age

The average length and weight at age in the landings are presented in Table 4 and Fig. 4. The vertical bars at each point in Fig. 4 represent the range of quarterly averages.

There is no major trend in mean lengths or weights among the years, although the mean lengths for 1961 are, on the average, about 1 cm below the other years in the first quarter (Table 4). The means of the second quarter are somewhat less than those of the first, particularly in weight, for almost all ages. This difference may be related to post spawning condition. The age composition of the two quarters is the same (see below) so that a size differential migration does not seem probable. It is not possible at this time to provide a full explanation.

The means for age groups 3-5 are undoubtedly over-estimates of the underlying population because fish of these ages are only partially recruited to the fishery, and we would expect a higher proportion of the faster growing fish to be retained by the trawl nets. Also, the means of the two youngest and two oldest age groups are over- and under-estimates, respectively, because of the lack of age assessments for the smaller fish of the youngest age groups, and the larger fish of the oldest age groups.

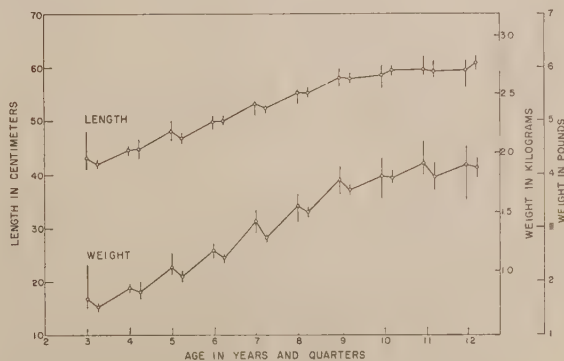


Fig. 4. Quarterly means of length and weight (gutted condition) at age in otter-trawl landings from Sampling Area 42.

TABLE 4. Average length (cm) and weight (lb., gutted) of haddock age groups in otter-trawl landings, Sampling Area 42, Division 4X. Average weights in parentheses are in kilograms.

		Age Group										Grand Mean
		3	4	5	6	7	8	9	10	11	12	
Year	Qtr.	Length										
1956	1	42.4	45.0	50.4	50.4	53.2	57.3	57.2	57.6	59.2	61.3	53.4
1957	1	43.5	45.4	48.6	51.2	55.6	55.9	60.1	60.0	60.2	61.6	54.2
1958	1	42.5	44.1	48.1	51.0	54.3	56.7	59.7	60.8	62.3	56.5	53.6
1959	1	41.5	44.9	47.7	50.2	54.9	55.3	58.4	59.0	60.9	58.0	53.1
1960	1	48.5	45.3	47.8	49.4	53.1	55.6	57.1	60.1	58.9	61.4	53.8
1961	1	41.7	45.0	47.0	49.1	51.7	53.9	57.7	56.3	59.1	60.6	52.1
Average		43.4	45.0	48.3	50.2	53.8	55.8	58.4	59.0	60.1	59.9	
1959	2	42.5	43.6	46.5	50.2	52.6	56.5	57.9	59.3	58.3	60.5	52.8
1960	2	42.5	46.8	48.0	50.9	53.2	55.2	59.0	60.6	61.5	62.1	54.0
Average		42.5	45.2	47.2	50.6	52.9	55.8	58.4	60.0	59.4	61.3	
Weight												
1956	1	1.57	1.88	2.58	2.59	2.98	3.67	3.62	3.71	4.01	4.35	2.63 (1.19)
1957	1	1.72	1.91	2.32	2.68	3.36	3.42	4.18	4.14	4.24	4.53	2.79 (1.27)
1958	1	1.58	1.82	2.31	2.69	3.23	3.64	4.19	4.36	4.64	3.54	2.73 (1.24)
1959	1	1.48	1.89	2.25	2.57	3.29	3.36	3.90	4.02	4.32	3.79	2.78 (1.26)
1960	1	2.35	1.96	2.30	2.52	3.07	3.49	3.85	4.28	4.07	4.58	2.81 (1.27)
1961	1	1.51	1.91	2.16	2.46	2.85	3.17	3.74	3.59	4.08	4.40	2.53 (1.15)
Average		1.70	1.90	2.32	2.59	3.14	3.46	3.92	4.02	4.24	4.21	
		(0.77)	(0.86)	(1.05)	(1.17)	(1.42)	(1.57)	(1.78)	(1.82)	(1.92)	(1.91)	
1959	2	1.55	1.69	2.01	2.48	2.81	3.42	3.64	3.89	3.69	4.01	2.48 (1.12)
1960	2	1.55	2.01	2.21	2.46	2.92	3.21	3.83	4.11	4.25	4.36	2.84 (1.29)
Average		1.55	1.85	2.11	2.47	2.86	3.32	3.74	4.00	3.97	4.18	
		(0.70)	(0.84)	(0.96)	(1.12)	(1.30)	(1.50)	(1.70)	(1.81)	(1.80)	(1.90)	

1.2 Index of relative abundance

An index of relative abundance in terms of landings-per-days-fished was derived from interview records of trips of large otter trawlers (150 to 300 Gross Tons) landing in Boston and fishing wholly within Sampling Area 42, primarily on Browns Bank. This fleet accounts for most of the otter-trawl catch of haddock within the area, although not all trips were interviewed.

The landings, days fished, and landings-per-days-fished of the interviewed fleet are presented in Table 5. The activity of this fleet is concentrated in the first quarter, when apparent abundance is high. There are very few trips upon which to base estimates in the other quarters, and no data are available for the third quarter in any year. However, even the limited data indicate a sharply reduced apparent abundance in the last three quarters of the year. Haddock spawn on Browns Bank during the first quarter (J. B. Colton, 1962, Report No. 62-11, Woods Hole

Bureau of Commercial Fisheries Biological Laboratory, unpublished), and the fish thus may be more densely concentrated at that time. Haddock tagged on inshore grounds off Lockeport, Nova Scotia during summer, were recaptured in fair numbers on Browns and Lahave banks the following winter, suggesting offshore winter movement (McCracken, 1956). Movement inshore in the summer has not been demonstrated, because haddock tagged on Browns Bank have yielded few returns from inshore areas (unpublished U.S. and Canadian records). However, the relative magnitude, and seasonal pattern of haddock movements in the area is difficult to ascertain from these data because of seasonal and geographical variations in fishing effort, and lack of sufficient tag returns.

Total effort for each quarter was estimated by dividing the total landings by the landings-per-days-fished (Table 5). Effort for the third quarter of each year was estimated using the average of the landings-per-day for the second and fourth quarters.

TABLE 5. Estimates of apparent abundance and total effort of otter trawls, Division 4X, Sampling Area 42. (Weight in lb. $\times 10^{-3}$).

Year	Qtr.	Interviewed Fleet				
		Days fished	Landings	Landings per day	Total Landings	Total Effort (days fished)
1956	1	298	7896	26.5	16348	617
	2	6	92	15.9	4770	300
	3	—	—	—	287	24
	4	4	25	6.3	636	100
	T			21.2	22042	1041
1957	1	201	3633	18.1	11506	636
	2	8	104	13.9	1485	107
	3	—	—	—	329	32
	4	15	133	8.7	832	96
	T			16.2	14151	871
1958	1	311	6065	19.5	19629	1007
	2	31	387	12.5	2206	176
	3	—	—	—	528	57
	4	26	146	5.5	676	123
	T			16.9	23039	1363
1959	1	80	1149	14.4	7243	503
	2	30	248	8.2	1905	232
	3	—	—	—	412	64
	4	18	56	3.2	364	114
	T			10.9	9924	913
1960	1	295	4232	14.4	12915	897
	2	34	371	10.9	2590	238
	3	—	—	—	516	49
	4	7	56	8.5	371	44
	T			13.3	16392	1228
1961	1	326	4530	13.9	14509	1045
	2	30	301	10.0	2451	245
	3	—	—	—	317	30
	4	—	—	—	193	19
	T			13.0	17470	1339

TABLE 6. Estimated numbers of fish landed per day fished by otter trawls in Sampling Area 42, Division 4X.

Year	Qtr.	Age Group										Totals of	
		3	4	5	6	7	8	9	10	11	12	Age groups	Length groups
1956	1	201	2512	1206	3014	1507	703	241	332	201	100	9884	10070
1957	1	324	584	2658	454	972	778	324	214	130	65	6483	6483
1958	1	30	998	1070	3423	570	499	285	143	21	26	7130	7140
1959	1	41	462	1386	1181	1181	257	308	194	82	30	5133	5211
1960	1	10	511	1074	1534	614	869	205	169	102	12	5114	5124
1961	1	66	602	1753	1260	1013	334	329	71	60	22	5477	5488
1959	2	19	619	912	424	619	189	209	195	65	9	3258	3311
1960	2	16	344	727	995	459	612	192	230	153	39	3827	3831

1.3 Relative abundance of age groups

The estimated numbers landed in each age group were divided by the appropriate days fished to provide estimates of abundance at age (Table 6 and Fig. 5). The magnitude of the inaccuracy in estimating numbers landed by not obtaining age assessments for every 2-cm length interval is indicated by the difference in the two total columns in Table 6.

The year classes of 1950, 1952, and 1954 are all relatively large, with that of 1952 being the largest of any of those included in the data. The 1949 year class may also have been relatively large since its abundance in 1956 at age 7 exceeded that of the 1952 year class at the same age. The abundance of the 1956 year class in 1961 at age 5 indicates it is moderately large.

Although the span of years is short, the data clearly show an alternation of year class abundance, the even numbered years yielding the greater abundance. The ratios of the sum of the numbers-per-day-fished for the two series of year classes at each age, given below, indicate that the difference persists throughout the range of age groups, although the ratio decreases with increasing age. At the present time we cannot specify the population processes which might generate such a system.

The average percentage age composition of landings in the first quarter, 1956-61, is given below and shows the highest frequency at age 6, with less than 1 percent of the landings in age groups 13 and above.

Although the apparent abundance in the second quarter is much lower than in the first, the percentage age distribution is similar for the two quarters in 1959 and 1960 combined, as shown below.

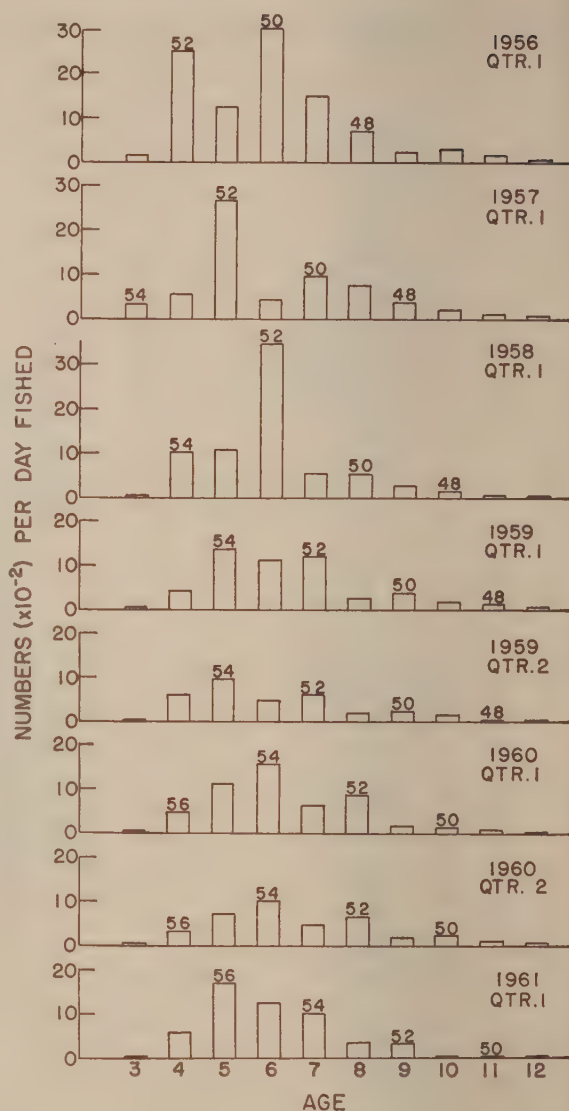


Fig. 5. Relative abundance of age groups in landings of haddock caught by otter trawlers in Sampling Area 42 of Division 4X. Numbers over bars denote year classes.

Age				4	5	6	7	8	9	10			
Even years/ odd years				2.4	1.7	2.8	1.2	1.5	1.3	1.3			
Age	3	4	5	6	7	8	9	10	11	12	13+		
%	2	14	24	28	15	9	4	3	2	<1	<1		
Age				3	4	5	6	7	8	9	10	11	12
Qtr. 1				1	9	24	26	18	11	5	4	2	1
Qtr. 2				1	14	23	20	15	11	6	6	3	1

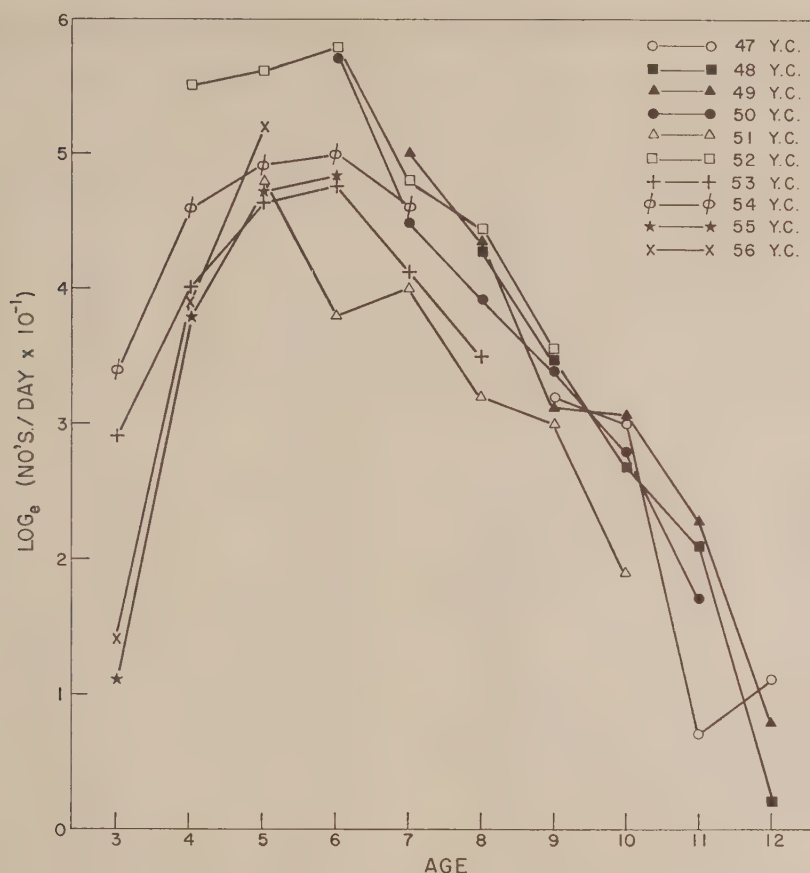


Fig. 6. Plot of logarithm of abundance on age for various year classes in landings by otter trawlers from Sampling Area 42, Division 4X.

1.4 Estimates of total mortality

The natural logarithms of numbers-per-day in the first quarter landings have been plotted against age for various year classes (Fig. 6). The peak of these curves occurs between 5 and 6 years of age, and recruitment is taken to be essentially complete by age 6. There is no observable departure from linearity between age groups 6 and 10, but the decrease in apparent abundance between age groups 10 and 12 appears somewhat greater. We might also note that the degree of homogeneity among the curves is rather satisfactory, considering the variety of data employed.

In order to estimate annual survival rates and examine variations thereof among years and ages, we have calculated the individual ratios

$$r_{ij} = \frac{N_{i+1, j+1}}{N_{ij}};$$

and the ratios of the means (i.e., ratio of sums of numerator and denominator above); $r_{.j}$, $r_{i.}$, and $r_{..}$, where N_{ij} is the estimated number-per-day in age group j , and year i , $i=1956, \dots, 1961$, and $j=3, \dots, 12$ years, and where the dot indicates the subscript over which the sums have been taken. The ratios $r_{i.}$ and $r_{..}$ include only age groups 6 through 12. The ratios are set forth in Table 7.

There is considerable variation among the r_{ij} , which is not unexpected considering all the possible sources of variation. The row and column totals are somewhat more informative.

Examination of the $r_{.j}$ reaffirms our previous observation that recruitment is essentially complete by age 6; the validity of this observation depends, of course, on constant mortality rates from age 6 onwards. We might conclude this is

TABLE 7. Estimates of total survival rate of haddock in first quarter otter-trawl landings from Sampling Area 42, Division 4X.

Year	Age Group									Age 6-12 Avg (r_{12})
	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	
1956-57	2.90	1.06	0.38	0.32	0.52	0.46	0.89	0.39	0.32	0.41
1957-58	3.08	1.83	1.29	1.26	0.51	0.37	0.44	0.10	0.20	0.54
1958-59	15.40	1.39	1.10	0.34	0.45	0.62	0.68	0.57	1.43	0.42
1959-60	12.46	2.32	1.11	0.52	0.74	0.80	0.55	0.52	0.15	0.62
1960-61	60.2	3.43	1.17	0.66	0.54	0.38	0.35	0.36	0.22	0.52
Avg (r_{12})	5.21	1.57	1.06	0.45	0.56	0.47	0.58	0.38	0.29	0.48 (r_{12})

so for ages 6-10, since there is no trend in the survival ratios. As mentioned earlier, the lack of age assessments for some of the larger length intervals has been responsible, to some extent, for the lower apparent abundance at ages 11 and 12.

The row averages, r_{12} , indicate large differences in survival among years. Changes in annual fishing intensity, show a general inverse trend to survival, but the series of data are too short and the yearly deviations are too small to permit a precise evaluation.

The overall pooled ratio, r_{12} , of 0.48 provides an estimate of survival which is equivalent to a total instantaneous mortality rate, Z , of 0.73. This may not be the "best" estimate of mortality in the statistical sense of no bias and minimum variance, but it seems as good as any with the data at hand. Other estimators (e.g., Robson and Chapman, 1961, and slope of the catch curve) have produced similar estimates in trial comparisons.

2. Hook and line fishery

The hook and line fishery in Sampling Area 42 is exclusively Canadian and employs both longlines and handlines. Longlines produce about two-thirds of the landings. Longliners use, on the average, 11 lines per tub and 50 hooks per line, or approximately 550 hooks per tub, (usually Pfluegers 6/0 or equivalent hook). Varying numbers of tubs per day are set depending upon fishing ground. Inshore vessels (0-25 gross tons) land catches daily whereas offshore vessels (above 25 gross tons) land after several days fishing.

Handliners (0-25 gross tons) use 6/0 hooks most frequently and fish the inshore grounds exclusively.

Landings from offshore areas (Subareas N and P, see Fig. 1) are at a peak in the first quarter, drop to a low level in the second and third quarters, and rise slightly again in the fourth quarter (Table 8). In contrast, landings from inshore areas (Subareas M, O, and Q) usually are highest in the second and third quarters. Consequently, total hook and line landings remain fairly steady throughout the year. Haddock landings from inshore areas constitute about three-fourths of the total hook and line landings of haddock each year.

Most hook and line landings were graded into market categories of large and serod at the time of sampling. Some fish were landed as ungraded, but the actual amount cannot be determined, because the total landings of the small longline vessels (0-25 gross tons) were listed as ungraded in the statistics, even though most of these landings actually were graded. Another deficiency in the statistics is that handline and longline landings usually were not recorded separately. Because complete statistics were lacking it was necessary to use special records of landings of Lockport longline vessels from Subareas N and O combined. The special records listed Lockport landings as large and serod for all classes of longliners, and this breakdown was used to prorate the total hook and line landings into large and serod for each month. This procedure requires several assumptions.

First, we have assumed that the length-frequencies of graded and ungraded catches are equal. This appears to be a valid assumption

TABLE 8. Haddock landings (gutted weight in lb. $\times 10^{-3}$) and numbers of fish measured and aged for hook and line fishery, Sampling Area 42, Division 4X.

Year	Qtr.	Landings			Number measured	Number aged
		M, O, Q (Inshore)	N, P (Offshore)	Total		
1956	1	1515.1	978.4	2493.5	1100	260
	2	1554.5	191.3	1745.8	—	—
	3	1473.7	167.6	1641.3	200	—
	4	1115.6	357.0	1472.6	800	200
	Total	5658.9	1694.3	7353.2		
1957	1	933.7	1507.4	2441.1	998	200
	2	1879.7	233.2	2112.9	1015	135
	3	2765.8	174.3	2940.1	290	50
	4	965.4	371.6	1337.0	2370	340
	Total	6544.6	2286.5	8831.1		
1958	1	796.2	1669.9	2466.1	400	56
	2	1627.4	161.8	1789.2	1515	227
	3	1475.7	270.1	1745.8	—	—
	4	1321.5	383.1	1704.6	1664	288
	Total	5220.8	2484.9	7705.7		
1959	1	883.0	1383.3	2266.3	332	55
	2	2681.1	290.9	2972.0	—	—
	3	2280.9	72.7	2353.6	425	331
	4	1420.7	124.4	1545.1	500	196
	Total	7265.7	1871.3	9137.0		
1960	1	590.7	1000.7	1591.4	230	47
	2	1553.9	437.7	1991.6	1000	192
	3	1754.0	91.1	1845.1	—	—
	4	736.4	311.2	1047.6	600	129
	Total	4635.0	1840.7	6475.7		
1961	1	1121.4	942.3	2063.7	—	—
	2	1612.1	263.3	1875.4	—	40
	3	2053.2	106.3	2159.5	—	79
	4	704.2	90.9	795.1	200	40
	Total	5490.9	1402.8	6893.7		

(Fig. 7). Also, we have assumed that the large serod ratio of Lockeport longliners as well as the length frequency of each market category was the same as that of the entire hook and line fleet. Supporting this assumption are the facts that most of the hook and line landings of haddock comes from Subareas N and O, and the size frequencies of both large and serod are similar for these two Subareas (Fig. 8).

However, the proportion of serod in offshore landings (Subarea N) tended to be lower than that of inshore landings (Subarea O), particularly in the first quarter (Table 9). Furthermore, Lockeport longliners land more haddock from offshore

grounds than from inshore grounds in the first part of the year and less from offshore grounds in the fourth quarter, than does the fleet in general (Table 10). Consequently, by using the combined landings from Subareas N and O in the Lockeport records we have obtained a slightly lower estimate of the proportion of serod in the total hook and line landings for the first two quarters, than that which would have been obtained by treating each area separately (Table 11). With the exception of 1958 the reverse is true for the fourth quarter (Table 11).

Finally our procedure assumes that the length-frequency of haddock landings is the same

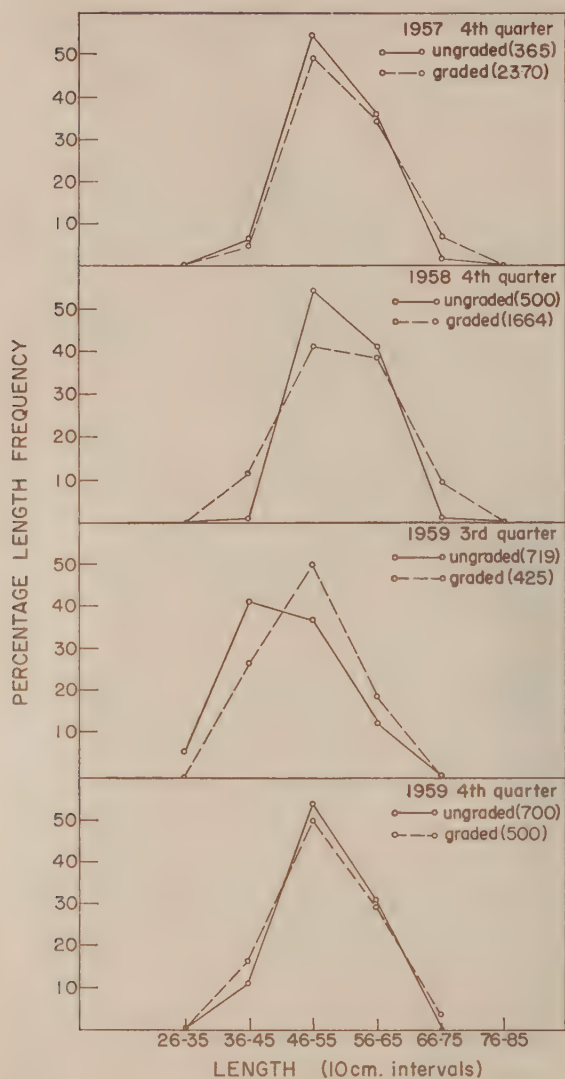


Fig. 7. Comparisons of graded (large and serod combined) and ungraded length-frequencies of Canadian longline landings of haddock caught in Sampling Area 42, Division 4X.

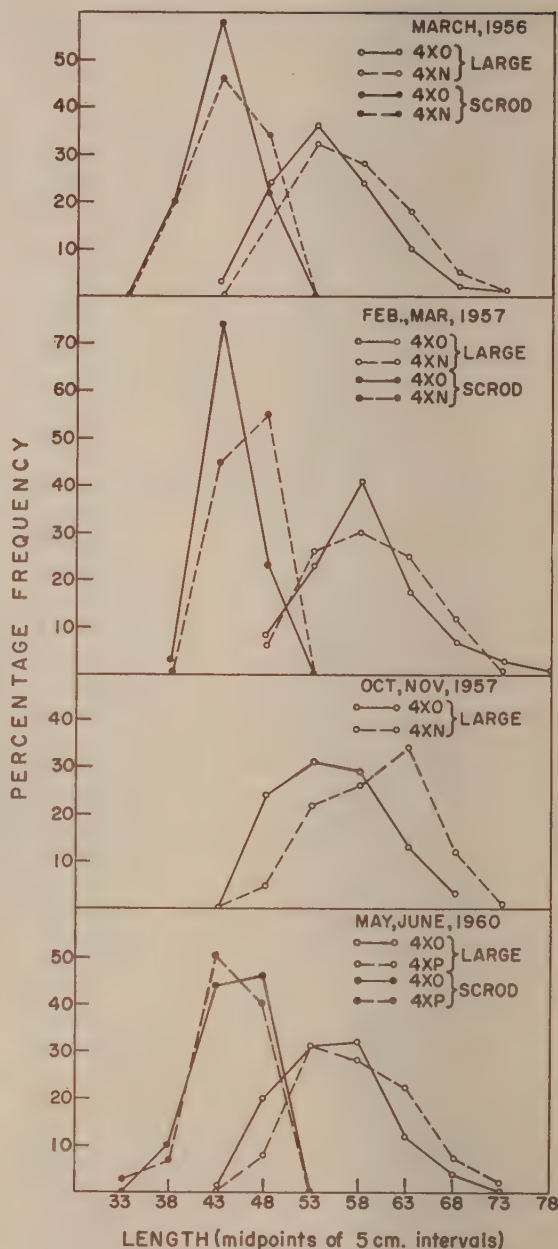


Fig. 8. Comparison of length frequencies of haddock in landings by longliners fishing in Subarea O (inshore) and Subareas N and P (offshore) of Sampling Area 42, Division 4X.

TABLE 9. Percentage (by weight) of serod in landings from offshore (Subarea N) and inshore (Subarea O) grounds by Lockeport longliners, Sampling Area 42, Division 4X.

Qtr.	1956		1957		1958	
	O	N	O	N	O	N
1	15	5	23	9	11	5
2	5	5	15	9	8	6
3	6	6	15	9	10	9
4	12	6	7	5	9	5

TABLE 10. Percentage contribution of offshore haddock landings to total haddock landings by Lockeport longliners, and to total haddock landings by entire hook and line fleet in Sampling Area 42, Division 4X.

Qtr.	1956		1957		1958	
	Lockeport line trawlers	Total hook and line	Lockeport line trawlers	Total hook and line	Lockeport line trawlers	Total hook and line
1	84	39	86	62	86	68
2	88	11	67	11	31	9
3	80	10	20	6	10	15
4	5	24	4	28	8	22

TABLE 11. Percentages (by weight) of serod in hook and line landings, estimated by using Lockeport Co. statistics of longline landings from Subareas N and O separately and combined.

Qtr.	1956		1957		1958	
	N and O Combined	N and O Separate	N and O Combined	N and O Separate	N and O Combined	N and O Separate
1	7	11	10	14	6	7
2	5	5	11	14	7	8
3	6	6	14	15	10	10
4	12	10	7	6	7	8

for handlines and longlines. Only two comparisons are available between length frequencies of landings by handline and longline vessels, and these indicate that there is some similarity between them (Fig. 9). Also the estimated proportion of serod is about the same for handliners as for longliners in the Lockeport Company records as shown below:

Year ^a	Longliners	Handliners
1957	13	11
1958	8	14
1959	16	18
1960	17	16
1961	25	18

Age-length frequencies of the hook and line landings were estimated in the manner described earlier. Length samples were used from graded longline landings only, but age samples were used regardless of grading or type of gear⁷. Inaccuracies because of lack of age assessments for all length intervals were negligible in this segment of data (see totals of Table 14).

2.1 Average length and weight at age

Mean length and weight at each age in hook and line landings are shown in Table 12 and Fig. 10. Mean length and weight in the fourth quarter was somewhat less in 1959 and 1960 than in the earlier years. In contrast, the means

^aOnly summer months with substantial handline landings were used in the comparison. Figures are arithmetic means of monthly percentage contributions of serod landings to total landings.

⁷Some samples were available from ungraded longline landings and a few samples were taken from handline landings.

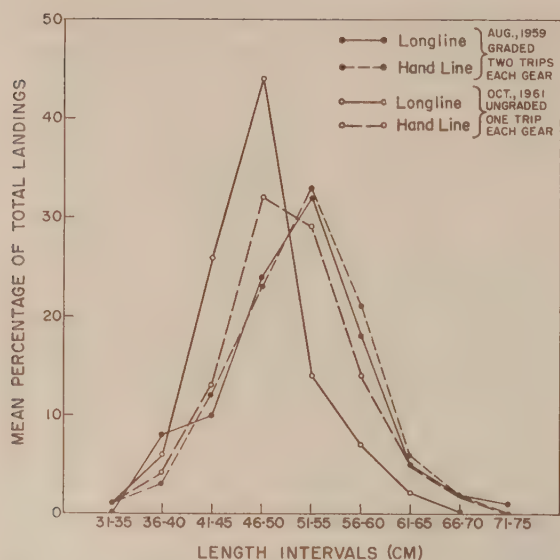


Fig. 9. Comparison of length frequencies of haddock in handline and longline landings from Sampling Area 42, Division 4X.

in the first and second quarters are somewhat greater in later years than in earlier years, but it seems likely that these differences lie within the limits of sampling error. In the first quarter only one age sample was obtained in each of the years 1958, 1959, and 1960; therefore, the means of lengths and weights at age for the first quarter are less reliable estimates than for the fourth quarter. Kohler (1960) presented data for inshore haddock landings at Lockeport during the period 1946-1954. Mean lengths at age in his study were approximately 1 cm higher than in the present study.

Lengths at age in fourth quarter longline landings were compared with those of the same year classes in the first quarter otter-trawl landings of the following year (Fig. 21). Haddock taken by otter trawls in the first quarter at ages 4 and 5 were larger than the corresponding age groups and year classes taken by longlines in the previous fourth quarter. From age 6 onward, haddock taken in the fourth quarter by longlines tended to be progressively larger than members of the same year classes and corresponding age groups taken by otter trawls in the following quarter. These differences are partly due to bias in estimating mean length of youngest and oldest age groups in otter-trawl landings. Differential selectivity by the two types of gear may also

contribute to the differences. However, the comparison may reflect real differences in length at age between inshore and offshore grounds; the former represented by longline landings, and the latter by otter-trawl landings.

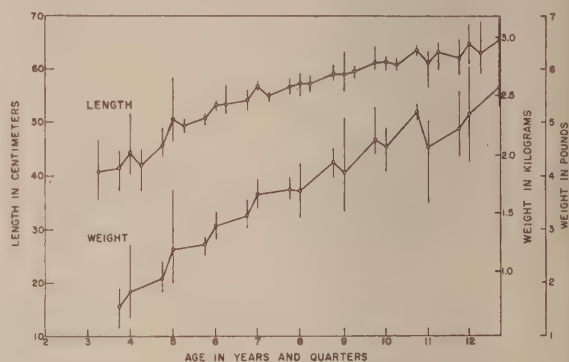


Fig. 10. Mean length and weight (guttled) of haddock in landings of longline vessels fishing in Sampling Area 42, Division 4X.

2.2 Index of relative abundance

Indices of relative abundance of haddock in terms of landings-per-line are based on special records of longliners landing at the Lockeport Company. The Lockeport Company data on landings, lines fished, and landings-per-line are given by quarters for inshore and offshore grounds in Table 13. The inshore indices are based on landings and effort of small (0-25 gross tons) and medium (26-50 gross tons) vessels fishing only in Subarea O. Offshore indices are based on data for medium longliners fishing mainly in Subarea N. No effort data are available for Subareas M, P, Q, and we have assumed that data for N are representative of P, and data for O representative of M and Q.

In inshore areas, abundance appears to have increased in the latter half of the period 1956-61 but chiefly in the second and third quarters (Table 13). Abundance indices in both the first and fourth quarters were about the same throughout the period except for the first quarter in 1961, which was about twice the average first-quarter value. While there is some basis for suggesting an overall increase in abundance on inshore grounds, the evidence is much less convincing than if all quarters had shown increases. Note also that abundance was higher on the average in the third and fourth quarters in all years.

TABLE 12. Average length (cm) and weight (lbs. gutted) of haddock age groups in longline landings. Sampling Area 42, Division 4X. Average weights in parentheses are in kilograms.

		Age Group										Grand Mean
		3	4	5	6	7	8	9	10	11	12	
Year	Qtr.	Length										
1956	4	44.7	46.7	51.4	55.1	57.2	59.6	61.4	63.9	61.4	67.1	54.6
1957	4	41.6	48.8	51.0	56.0	58.1	60.8	64.2	64.5	64.7	59.9	54.4
1958	4	42.7	44.6	50.7	53.9	56.9	58.9	60.2	63.0	60.4	69.4	54.8
1959	4	41.5	45.9	49.7	53.2	56.5	60.0	60.9	63.7	65.8	64.5	52.7
1960	4	37.4	43.7	51.4	52.4	55.5	57.9	60.1	64.5	59.4	68.0	51.9
Average		41.6	45.9	50.8	54.1	56.8	59.4	61.4	63.9	62.3	65.8	
1956	1		45.4	51.4	53.3	56.6	58.9	60.0	61.2	63.6	64.2	55.9
1957	1		43.2	48.4	54.0	56.5	59.1	63.2	62.1	62.4	62.8	55.6
1958	1		40.5	47.2	54.0	57.6	56.1	56.0	62.5	61.6	68.5	56.2
1959	1		40.5	46.5	52.5	56.1	56.6	59.7	60.8	56.8	61.2	56.2
1960	1		51.6	58.5	52.2	57.6	55.0	56.2	61.9	62.8	67.6	58.2
Average			44.2	50.4	53.2	56.9	57.1	59.0	61.7	61.4	64.9	
1957	2	35.6	37.3	50.5	57.0	55.3	58.7	60.8	60.6	65.1	69.2	50.4
1958	2	40.5	45.0	49.1	52.5	54.0	56.1	58.7	60.0	60.1	59.5	54.4
1960	2	46.5	43.8	48.2	51.7	55.6	57.2	59.5	62.2	65.0	60.9	55.0
Average		40.9	42.0	49.3	53.7	55.0	57.3	59.7	60.9	63.4	63.2	
Weight												
1956	4	1.89	2.14	2.78	3.40	3.77	4.26	4.62	5.15	4.59	5.99	3.41 (1.55)
1957	4	1.56	2.41	2.75	3.57	3.98	4.51	5.31	5.36	5.38	4.35	3.40 (1.54)
1958	4	1.71	1.93	2.76	3.24	3.81	4.16	4.48	5.05	4.50	6.53	3.50 (1.59)
1959	4	1.55	2.04	2.53	3.06	3.65	4.36	4.55	5.13	5.59	5.30	3.10 (1.41)
1960	4	1.16	1.82	2.86	3.04	3.58	3.99	4.42	5.30	4.39	6.15	3.05 (1.38)
Average		1.57 (0.71)	2.07 (0.94)	2.74 (1.24)	3.26 (1.48)	3.76 (1.70)	4.26 (1.93)	4.68 (2.36)	5.20 (2.22)	4.89 (2.57)	5.66	
1956	1		1.95	2.77	3.04	3.57	4.00	4.19	4.42	4.93	4.95	3.52 (1.60)
1957	1		1.73	2.48	3.34	3.73	4.23	5.09	4.88	5.02	4.96	3.70 (1.68)
1958	1		1.45	2.24	3.33	3.93	3.66	3.70	4.90	4.70	6.15	3.73 (1.69)
1959	1		1.35	2.01	2.81	3.40	3.52	4.07	4.19	3.50	4.29	3.50 (1.59)
1960	1		2.72	3.75	2.90	3.62	3.21	3.37	4.43	4.66	5.62	3.82 (1.73)
Average			1.84 (0.83)	2.65 (1.20)	3.08 (1.40)	3.65 (1.65)	3.72 (1.69)	4.08 (1.85)	4.56 (2.07)	4.57 (2.07)	5.19 (2.35)	

The annual trend in abundance is less noticeable on offshore grounds, but the lowest abundance indices occurred in 1956 and 1957 as was the case for inshore grounds. In each year there is a marked peak of abundance in the first quarter, and on the average the lowest abundance occurs in the third quarter.

Abundance estimates for the offshore grounds are probably less reliable than for inshore grounds because fewer interviews for offshore trips were recorded, particularly in the third and fourth quarters.

Nevertheless, the fact that the peak offshore abundance occurs in the first quarter of both otter trawl and longline fisheries, and that the third and fourth quarters show highest abundance in the inshore longline fishery, suggests again that haddock move offshore in winter and inshore in summer.

Total hook and line effort, in terms of lines, was estimated by dividing total hook and line landings from each ground by estimated landings per line (Table 13). The total estimated number of lines fished has declined steadily.

TABLE 13. Estimates of apparent abundance and total effort of hook and line vessels (in terms of lines) in Sampling Area 42, Division 4X. Abundance estimates based on records of Lockport Company.

Year	Qtr.	Inshore* (M, O, Q)					Offshore (N, P)				
		Lockport Co. Special Records					Lockport Co. Special Records				
		No. Trips	Lines Fished	Landings (lb.)	Landings per Line	Total Landings (lb. x 10 ⁻⁴)	No. Trips	Lines Fished	Landings (lb.)	Landings per Line	Total Landings (lb. x 10 ⁻⁴)
1956	1	182	14575	65065	4.5	1515.1	29	11121	331055	29.8	978.4
	2	68	3553	4675	1.3	1554.5	24	10593	53760	5.1	191.3
	3	89	4741	23010	4.8	1473.7	35	13409	95590	7.1	167.6
	4	235	24750	285880	11.6	1115.6	4	1342	14640	10.9	357.0
	TOTAL		47619	378630	$\bar{x} = 8.0$	193.6		36465	495045	$\bar{x} = 13.6$	206.4
1957	1	162	15928	89090	5.6	933.7	46	16258	413750	25.4	1507.4
	2	112	6952	29275	4.2	1879.7	22	6941	59140	8.5	233.2
	3	127	6226	84090	13.5	2765.8	18	4499	20860	4.6	174.3
	4	235	22770	234715	10.3	965.4	3	1166	9750	8.4	371.6
	TOTAL		51876	437170	$\bar{x} = 8.4$	91.4		28864	503500	$\bar{x} = 17.4$	16.8
1958	1	105	9966	65015	6.5	796.2	43	14091	414895	29.4	1669.9
	2	175	11902	75025	6.3	1627.4	15	4433	34165	7.7	161.8
	3	169	11286	102160	9.0	1475.7	5	11505	11505	7.0	270.1
	4	210	22275	223480	10.0	1321.5	6	2046	32315	15.8	383.1
	TOTAL		55429	465680	$\bar{x} = 8.4$	67.6		22220	492880	$\bar{x} = 22.2$	14.0
1959	1	70	7029	37815	5.4	883.0	44	16654	424063	25.5	1383.3
	2	108	4873	53290	10.9	2681.1	12	4499	57865	12.9	290.9
	3	125	3245	45585	14.0	2280.9	0	-	-	-	72.7
	4	77	8646	105715	12.2	1420.7	0	-	-	-	124.4
	TOTAL		23793	242405	$\bar{x} = 10.2$	68.9		21153	481928	$\bar{x} = 22.8$	9.1
1960	1	58	5489	33055	6.0	590.7	35	12694	390145	30.7	1000.7
	2	55	1771	17130	9.7	1553.9	14	7040	182905	26.0	437.7
	3	71	1683	22735	13.5	1754.0	2	528	3585	6.8	91.1
	4	88	8459	86160	10.2	736.4	10	3454	38925	11.3	311.2
	TOTAL		17402	159080	$\bar{x} = 9.1$	46.0		23716	615560	$\bar{x} = 26.0$	9.0
1961	1	56	6908	95270	13.8	1121.4	15	5203	179510	34.5	942.3
	2	60	2255	24635	10.9	1612.1	11	4642	42730	9.2	263.3
	3	150	3421	73570	21.5	2053.2	2	935	5955	6.4	106.3
	4	49	4884	53060	10.9	704.2	10	2541	15580	6.1	90.9
	TOTAL		17468	246535	$\bar{x} = 14.1$	38.9		13321	243775	$\bar{x} = 18.3$	8.8
											47.7

†Inshore plus offshore.

*Estimated by using inshore catch/line.

TABLE 14. Estimated numbers of fish ($\times 10^2$) landed per line by age groups, ¹ Sampling Area 42, Division 4X.

Year	Qtr.	Age Group										Totals of	
		3	4	5	6	7	8	9	10	11	12	Age groups	Length groups
1956	4	15	59	32	79	65	40	21	10	3	5	4280	4322
1957	4	12	29	109	29	52	17	13	5	9	2	3917	3935
1958	4	5	39	33	103	27	42	25	14	8	4	4844	4873
1959	4	20	76	82	53	88	22	31	4	6	2	4981	4990
1960	4	5	96	47	74	24	64	17	4	7	2	3398	3434
Avg		11.4	59.8	60.6	67.6	51.2	37.0	21.4	7.4	6.6	3.0		
1956	1		17	15	52	37	24	15	20	4	4	7089	7089
1957	1		8	85	27	48	43	28	26	13	8	6606	6606
1958	1		2	16	126	33	85	37	6	48	4	6492	6617
1959	1		6	30	19	87	39	35	35	11	10	6148	6367
1960	1		19	9	39	53	51	27	70	30	23	4169	4169
Avg			10.4	31.0	52.6	51.6	48.4	28.4	31.4	21.2	9.8		

¹Note that fish of a given year and age group in Quarter 4 are just $\frac{1}{4}$ year younger than the next older age group in Quarter 1 of the following year.

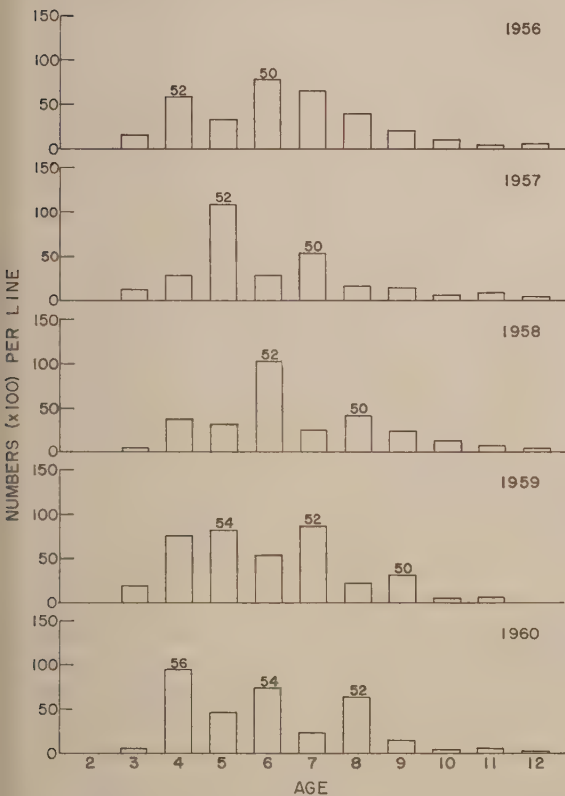


Fig. 11. Relative abundance of age groups in landings of hook and line vessels fishing in Sampling Area 42, Division 4X. Numbers above bars denote year classes.

2.3 Relative abundance of age groups

Estimated numbers landed at each age in the first and fourth quarters were divided by the estimated total lines fished (inshore and offshore grounds combined) to obtain estimates of abundance at each age (Table 14 and Fig. 11).

The fourth quarter was the only one in which age sampling was at all adequate for more than two successive years. Data for the years 1958, 1959, and 1960 in the first quarter are rather inadequate, and estimates of abundance at age are less reliable than for the fourth quarter.

Relative numbers landed per line in the fourth quarter show the alternating strengths of even and odd year classes which was shown previously in the otter trawl landings. The 1952 year class appears to have been a particularly strong year class and the early estimates indicate that the 1956 year class may be of comparable size. In general, the estimates of relative abundance of year classes derived from otter-trawl and longline landings agree very favourably.

The percentage age composition shown below indicates a maximum contribution to longline landings at age 6, which is the same as that for otter trawl landings. Age groups 10 and older contributed an average of nearly 15 per cent to hook and line landings, as compared to less than 6 percent of first quarter otter-trawl landings.

Period	Percentage of longline landings at age										
	3	4	5	6	7	8	9	10	11	12	13+
Qtr. 1 (1956-1960)	-	4	11	18	18	16	10	11	6	3	2
Qtr. 2 (1957, 1958, 1960)	4	6	15	19	14	19	9	5	4	2	3
Qtr. 4 (1956-1960)	3	18	19	21	15	11	6	2	2	1	1

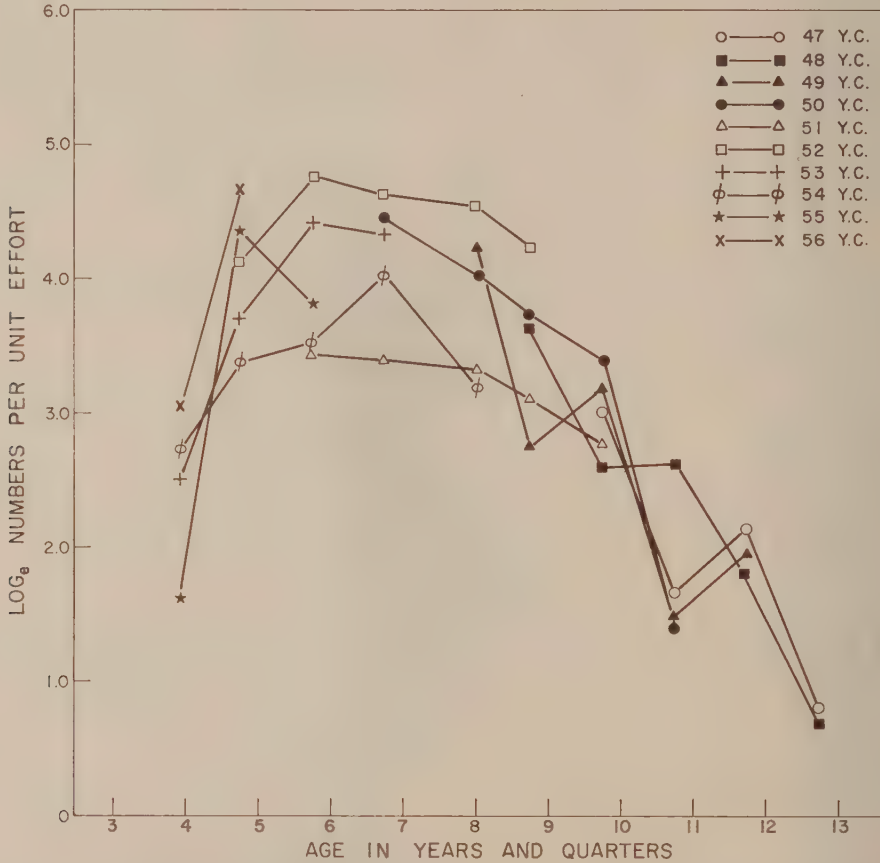


Fig. 12. Logarithmic abundance of haddock year classes at age in landings of longliners fishing in Sampling Area 42, Division 4X.

2.4 Estimates of total mortality

Catch curves based on fourth quarter longline landings were plotted for individual year classes (Fig. 12). The rather wide scatter of points between different year classes and also by the same year class in successive years indicates a fair degree of sampling variation and does not provide a good basis for judging linearity of the right hand limb of the curves. However, the wide dome, and apparent convexity of the curve over a large range of ages may be indicative of a

rather gradual recruitment, which is probably not complete until age 8. In contrast, recruitment was found to be nearly complete at age 6 in otter-trawl landings.

Estimates of survival from age 6 on were made using the ratios r_{ij} , r_i , r_j , and r as defined in the previous section, and are set forth in Table 15. The estimated survival ratio of 0.96 for 1957-58 is unrealistic and therefore, the value of $r = 0.64$ is considered to be high also.

TABLE 15. Estimates of total survival rate of haddock in fourth quarter hook and line landings, Sampling Area 42, Division 4X.

Year	Age Group									Mean (r_i)
	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	Age 6-12
1956-57	1.93	1.85	0.91	0.66	0.26	0.32	0.24	0.90	0.67	0.45
1957-58	3.25	1.14	0.94	0.93	0.81	1.47	1.08	1.60	0.44	0.96
1958-59	15.20	2.10	1.61	0.85	0.81	0.74	0.16	0.43	0.25	0.70
1959-60	4.80	0.62	0.90	0.45	0.73	0.77	0.13	1.75	0.33	0.58
Mean (r_j)	4.62	1.33	1.01	0.72	0.62	0.71	0.30	0.91	0.38	0.64 (r.)

We believe the rather wide fluctuation in survival estimates between years is caused by errors in abundance estimates, which would affect all age groups in a given year. It should be recalled that in the fourth quarter about one-fourth of the total hook and line landings were from offshore grounds (N, P) but usually there were never more than 10 offshore trips recorded in the fourth quarter for any year, and there were only 3 and 6 trips in 1957 and 1958, respectively (Table 13). Rather large errors might be expected, therefore, in estimating offshore abundance in the fourth quarter, and these errors could significantly affect the estimate of total effort.

Under these conditions, a more accurate estimate of mortality probably is obtained by plotting natural logarithms of the mean numbers-landed-per-line at each age for the fourth quarter (Fig. 13). Linear regression of the points from ages 7-12 gives a slope of -0.58 , i.e., $Z = 0.58$.

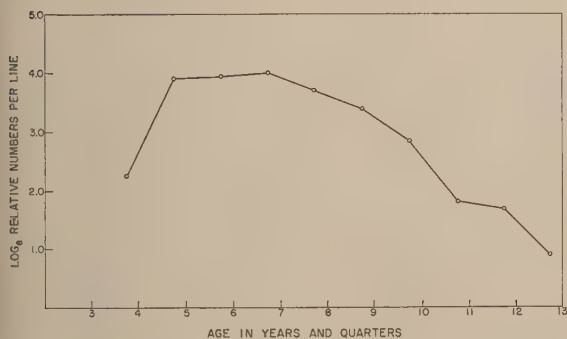


Fig. 13. Logarithms of mean numbers-landed-per-line on age for haddock in hook and line landings from Sampling Area 42, Division 4X.

3. Comparison of mortality estimates from line and trawl landings

For purposes of comparison, we have computed the difference between $\log_e$ of mean numbers per unit effort of successive age groups, i.e., the instantaneous total mortality, for both longlines and otter trawls in the years 1956-1960. Plotting these differences against age groups (Fig. 14) indicates that estimates of mortality in both sets of data approach the same value at older ages. However, while the estimates from otter trawl landings vary around a nearly constant value from ages 6-7 onward, the estimates from longline landings approach the limiting value more slowly, and can be considered as estimates of a constant value only from ages 8-9 onwards.

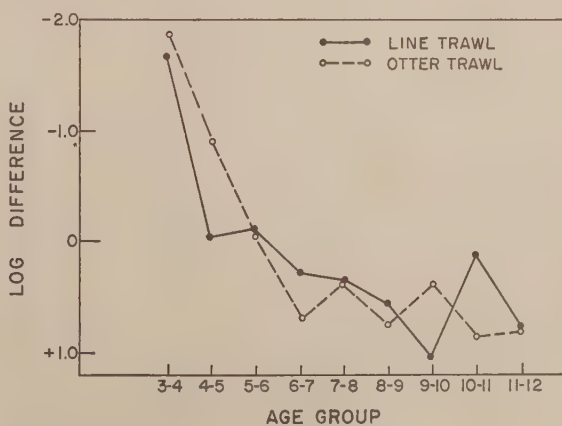


Fig. 14. Estimates of instantaneous total mortality (log difference) between successive ages of haddock in longline and otter-trawl landings.

Although the data are somewhat variable for firm conclusions, the overall picture is what we might expect with a more gradual recruitment to hook and line gear producing a lower fishing mortality among the younger age groups. A total instantaneous mortality rate, Z , of about 0.7 for ages 8 onwards for the whole haddock stock of southern Nova Scotia is considered a reasonable estimate, while the overall rate would decrease in age groups 6 and 7 in proportion to the amount of hook and line catch. Below age 6, the fishing mortality is drastically reduced because of incomplete recruitment to both kinds of gear.

Sampling Area 41, (Bay of Fundy)

The fishery within this area is carried on primarily by Canadian small and medium otter trawlers in the second and third quarters (Table 16). The smaller U.S. otter-trawl fishery is carried on in the third and fourth quarters. The longline fishery accounted for 47 percent of the

landings in 1956, but this share of the landings had dropped to 25 percent in 1957, and to 10 percent by 1961.

No otoliths were collected in 1956, thus analysis of that year's landings is not possible. Length and age samples are available only for Canadian otter-trawl landings in the second quarter of the four years, 1958-1961 (Table 16), and it has been necessary to prorate the U.S. landings in the second quarter by the Canadian length-frequency data. Comparison of the length frequencies of haddock in landings of the two countries for the third quarter indicate that Canadian landings are composed of smaller fish (Fig. 15). This probably applies to all seasons. However, because of the small amount of U.S. landings in the second quarter (1.5 percent on the average), the bias introduced by the proration is negligible. Both U.S. and Canadian length-samples are available for the third quarter of 1957-59, and 1961; and for the fourth quarter

TABLE 16. Landings of haddock (guttled weight, lb. $\times 10^{-3}$) and numbers of fish measured and aged for otter-trawl fishery, Sampling Area 41, Division 4X.

Year	Qtr.	Landings			Measured		Aged
		CAN.	U.S.	Total	CAN.	U.S.	
1956	1	81	—	81	—	—	—
	2	1542	49	1590	—	—	—
	3	1556	908	2464	—	1501	—
	4	443	457	900	—	280	—
1957	1	78	—	78	—	—	—
	2	1604	20	1624	—	63	—
	3	2614	442	3056	200	445	142
	4	783	395	1178	—	150	—
1958	1	144	—	144	202	—	40
	2	2310	34	2343	3815	—	445
	3	3003	592	3595	2753	434	233
	4	497	164	661	—	159	34
1959	1	222	—	222	—	—	—
	2	2320	30	2350	2060	—	166
	3	3233	855	4088	2100	647	372
	4	417	244	661	173	522	35
1960	1	338	—	338	—	—	—
	2	2287	29	2316	1800	—	267
	3	3036	636	3672	—	267	—
	4	470	302	772	3000	194	472
1961	1	181	—	181	—	—	—
	2	2116	26	2142	2500	—	268
	3	3890	683	4572	567	433	194
	4	833	18	851	150	—	30

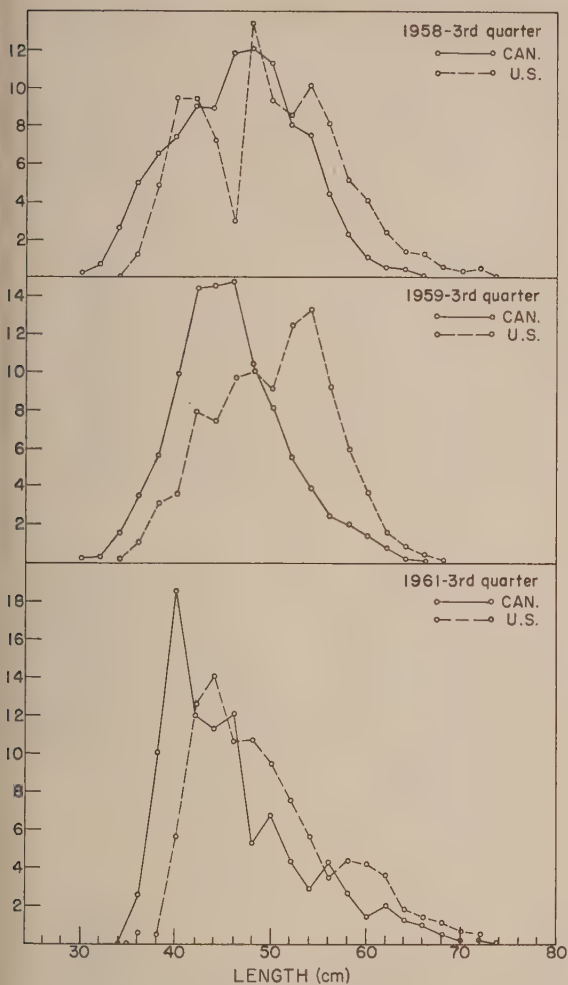


Fig. 15. Comparison of length frequencies of haddock in Canadian and U.S. landings from Sampling Area 41, Division 4X.

of 1960. Biostatistics of the landings of each country were computed in the standard manner for these quarters, and pooled to form total figures for analysis.

Data on length and age frequency of longline landings were not obtained. Therefore, it is not possible to estimate length and age composition of these landings.

1. Average length and weight

The mean lengths and weights of each age group are presented in Table 17 and Fig. 16. The means for the third and fourth quarters of each year were obtained by weighting the esti-

mates of mean length and weight at age in landings of each country by the estimated numbers and weights landed, respectively, in each country. Annual estimates are simple arithmetic averages. Vertical bars in Fig. 16 represent the range of quarterly estimates.

The lengths and weights of the 2- and, to a lesser extent, 3-year-old age groups are biased upward because of incomplete recruitment. Length and weight at age seems fairly consistent throughout the study period, and the apparent growth rate fairly rapid. Asymptotic maximums appear to be about 70 cm or 6 pounds (2.7 kg).

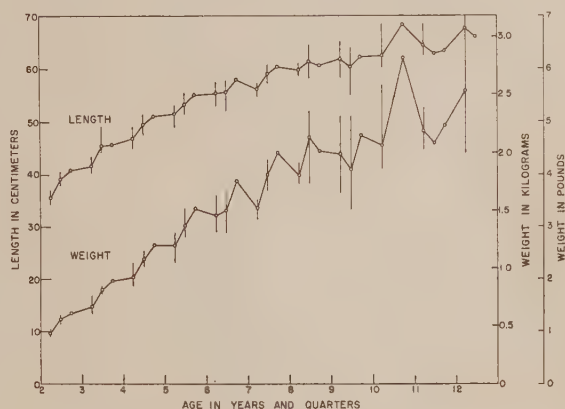


Fig. 16. Mean length and weight (gutted) of haddock in landings of otter trawls fishing in Sampling Area 41, Division 4X.

2. Index of relative abundance

Estimates of relative abundance for the second quarter were based on Canadian log-book records of small otter trawlers. These logs give the number of hours the trawl net was fishing, and the corresponding catch. From these data an estimated apparent abundance index in terms of catch-per-hour of fishing was obtained. The total effort was estimated by dividing the total landings (including those of longlines) by the above index (Table 18).

A similar procedure was used for the third and fourth quarter indices. The data employed were from interview records of medium-sized otter trawlers landing in the U.S. and the index is in terms of landings-per-day fished. These estimates are also found in Table 18.

The two sets of indices are not directly comparable, because of the different effort units and vessel class.

TABLE 17. Average length (cm) and weight (lb., gutted) of haddock age groups in otter-trawl landings, Sampling Area 41, Division 4X. Average weights in parentheses are in kilograms.

		Age Group											Grand Mean
Year	Qtr.	2	3	4	5	6	7	8	9	10	11	12	
Length													
1957	3	40.3	49.2	51.5	53.3	57.7	—	58.5	64.1	58.5	—	60.5	49.79
1958	2	36.8	41.7	49.1	52.6	56.3	57.3	59.0	65.1	60.5	62.5	—	45.65
1958	3	37.9	44.4	50.1	51.8	55.4	—	64.5	55.0	—	—	—	47.22
1959	2	34.5	40.6	45.4	49.3	53.4	55.1	59.7	58.5	68.5	68.5	64.5	44.40
1959	3	38.7	44.6	47.8	53.1	52.3	57.5	58.5	58.5	—	—	72.5	46.76
1960	2	—	43.6	47.1	53.0	57.8	57.0	61.2	63.2	61.0	64.0	62.5	50.43
1960	4	40.8	45.9	51.1	55.2	58.1	60.5	60.3	62.2	68.4	63.1	—	50.69
1961	2	35.9	40.8	45.4	50.6	53.8	55.3	59.8	61.1	60.5	66.0	72.5	44.84
1961	3	40.4	44.2	49.0	55.5	57.7	60.9	64.3	63.9	—	62.5	—	46.88
Avg	2	35.7	41.7	46.8	51.4	55.3	56.2	59.9	62.0	62.6	64.2	67.5	
Avg	3	39.3	45.6	49.6	53.4	55.8	59.2	61.4	60.3	—	62.8	66.5	
Weight													
1958	2	1.05	1.49	2.32	2.83	3.43	3.52	3.83	5.10	4.11	4.49	—	1.98 (0.90)
1958	3	1.17	1.81	2.57	2.81	3.39	—	5.05	3.35	—	—	—	2.25 (1.02)
1959	2	0.87	1.38	1.88	2.36	2.92	3.18	3.85	3.65	5.70	4.80	—	1.83 (0.83)
1959	3	1.24	1.85	2.26	3.02	2.88	3.72	3.93	3.87	—	—	—	2.18 (0.99)
1960	2	—	1.68	2.09	2.88	3.61	3.50	4.23	4.54	4.33	4.78	4.40	2.60 (1.18)
1960	4	1.37	1.99	2.72	3.37	3.90	4.46	4.43	4.78	6.25	4.91	—	2.94 (1.33)
1961	2	0.99	1.40	1.87	2.56	3.00	3.24	4.03	4.28	4.10	5.26	6.80	1.89 (0.86)
1961	3	1.36	1.77	2.39	3.37	3.73	4.29	5.20	5.11	—	4.60	—	2.21 (1.00)
Avg	2	0.97	1.49	2.04	2.66	3.24	3.37	3.98	4.39	4.56	4.83	5.60	
		(0.44)	(0.67)	(0.93)	(1.21)	(1.47)	(1.53)	(1.80)	(1.99)	(2.07)	(2.19)		
Avg	3	1.26	1.81	2.40	3.06	3.33	4.00	4.72	4.10	—	4.60	—	
		(0.57)	(0.82)	(1.09)	(1.39)	(1.51)	(1.81)	(2.14)	(1.86)		(2.09)		

Fishing effort, landings, and apparent abundance have remained fairly steady throughout the period. Although we have no measure of the reliability of these estimates, the amount of data upon which they are based is small and therefore the variability may be large.

3. Relative abundance of age groups

The estimated numbers of each age group landed in each quarter were divided by the corresponding total effort to estimate the relative abundance of age groups in terms of numbers-per-day or hour of fishing. The two sets of these data are presented in Table 19. Because the abundance indices are not comparable, the second quarter estimates must be treated independently of those of the third and fourth quarters.

Examination of abundance of 3-year-old age groups in the third quarter (Fig. 17) reveals comparatively strong 1954, 1956, and 1958 year

classes, the latter being the largest of those included in the data. The 1952 year class also appears strong, although only the remnants from age 5 onwards are observable in the years under study. The 1959 year class, just entering the fishery as 2-year-olds in 1961, is larger at this age than any in previous years. Fluctuations in relative abundance of year classes are dampened in the older age groups.

Abundance data for the second quarter follow similar trends, but reflect less variability among year classes.

Plots of natural logarithms of abundance against age for various year classes in the second quarter (Fig. 18), and in the third and fourth quarters (Fig. 19) indicate maximum abundance occurs at age 3 in all cases except for year class 1957 in the fourth quarter. There is no observable departure from linearity in either of the catch curves beyond age 3; in fact, they are remarkably

straight. Also, with proper adjustment of abundance magnitude, the two sets of curves are nearly coincident. We shall assume, therefore, that haddock are fully recruited to the otter trawl fishery by age 3. Considering the many possible

sources of variation in the estimation of abundance, the catch curves of the various year classes reflect a marked degree of homogeneity. This homogeneity provides a measure of confidence in the final results.

TABLE 18. Estimation of apparent abundance of haddock and total effort in otter-trawl-days or hours for Sampling Area 41, Division 4X.

Year	Qtr.	Interviewed Fleet			Total landings OT plus LT (lb. x 10 ⁻³)	Total effort (days or hours x 10 ⁻²)
		Landings (lb. x 10 ⁻³)	Days or hours ¹	Landings/day or hour (lb. x 10 ⁻³)		
1957	1	—	—	—	—	—
	2	—	—	—	—	—
	3	240.0	35.0	6.8	3413	502
	4	—	—	—	—	—
1958	1	—	—	—	—	—
	2	28.5	173.0	0.17	3147	185
	3	445.3	80.6	5.5	4228	769
	4	—	—	—	—	—
1959	1	—	—	—	—	—
	2	38.9	207.0	0.19	2803	148
	3	560.6	93.9	6.0	4567	761
1960	1	—	—	—	—	—
	2	61.1	307.0	0.20	2668	133
	3	379.1	59.5	6.4	4024	629
	4	180.4	33.9	5.3	983	185
1961	1	—	—	—	—	—
	2	33.6	357.0	0.10	2419	242
	3	209.0	29.9	7.0	4831	690
	4	—	—	—	—	—

¹U.S. med. OT's for Qtr. 3 and 4 - days
Can. small OT's for Qtr. 2 - hours

TABLE 19. Numbers of haddock landed per day or hour fished by otter trawlers for various years and quarters, Sampling Area 41, Division 4X.

Year	Qtr.	Numbers per day fished at age								Totals of	
		2	3	4	5	6	7	8	9+	Age groups	Length groups
1957	3	264	1139	472	408	47	—	12	34	2376	2382
1958	3	258	741	630	237	148	—	5	32	2051	2090
1959	3	264	1041	671	318	87	60	26	8	2453	2477
1960	4	382	416	349	164	151	36	59	38	1596	1617
1961	3	550	1412	559	194	112	41	50	85	3003	3019
Year	Qtr.	Numbers per hour fished at age								Totals of	
		2	3	4	5	6	7	8	9+	Age groups	Length groups
1958	2	2.5	33.4	17.2	5.0	3.8	0.6	0.6	0.5	63.6	64.0
1959	2	0.6	37.8	29.8	7.0	2.6	4.5	0.4	1.0	83.8	86.6
1960	2	0	16.0	21.3	14.0	4.6	1.3	5.3	3.2	66.5	67.0
1961	2	0.9	22.5	11.0	5.9	3.2	1.4	0.9	0.8	45.9	46.8

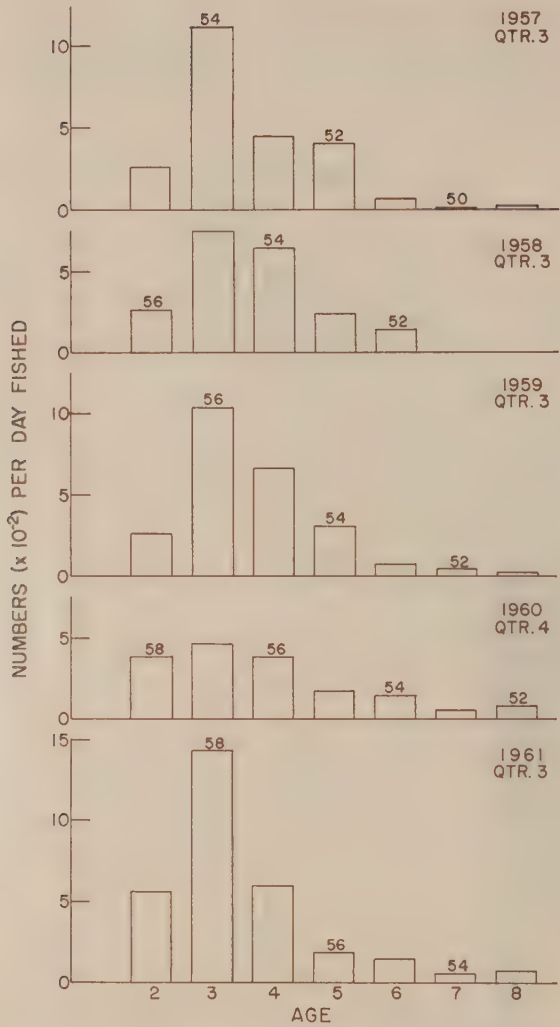


Fig. 17. Relative abundance of age groups of haddock in otter-trawl landings from Sampling Area 41, Division 4X. Numbers above bars denote year classes.

The average percentage age composition for both seasons is presented below:

Age	2	3	4	5	6	7	8	9+
Qtr. 2	2	42	30	13	5	3	3	2
Qtr. 3	15	41	23	12	5	1	1	2

The greater proportion of 2-year-olds in third quarter landings probably reflects recruitment to the fishery at this time. There are few fish over 6 years of age in the landings.

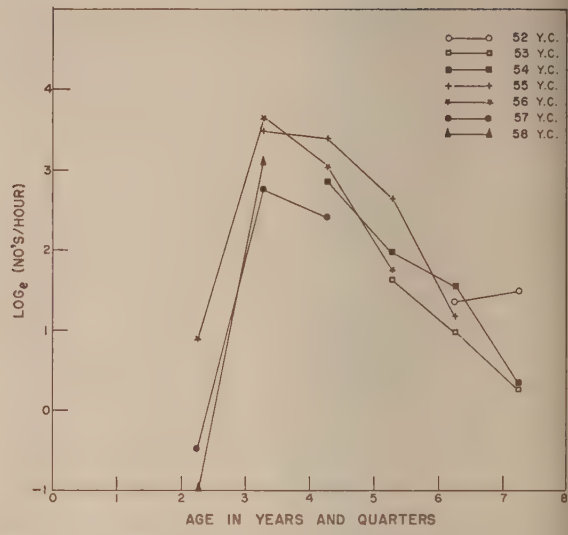


Fig. 18. Logarithms of abundance of haddock on age for otter-trawl landings from Sampling Area 41 in the second quarter.

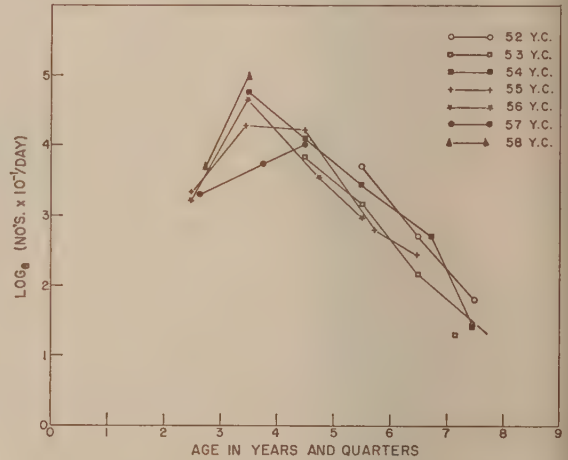


Fig. 19. Logarithms of abundance of haddock on age for otter-trawl landings from Sampling Area 41 in the third and fourth quarters.

4. Estimated survival rate

Survival rates were estimated from both sets of data as outlined in previous sections (Table 20). The estimates of average total annual survival rate were based on age groups 3 through 7, except for the period 1960, fourth quarter, to 1961, third quarter, where age groups 4 through 7 were used.

Estimates of abundance were not determined for quarter three in 1960, but those for quarter

TABLE 20. Estimated annual survival rate and corresponding instantaneous mortality rate, Z, Sampling Area 41.

Year (Qtr.)	Age Group					Avg Age groups 3-7	Z
	2-3	3-4	4-5	5-6	6-7		
1957(3rd.)-1958(3rd.)	2.81	0.55	0.50	0.36	—	0.50	
1958(3rd.)-1959(3rd.)	4.03	0.90	0.50	0.37	0.40	0.65	
1959(3rd.)-1960(4th.): 5/4 year	1.58	0.34	0.24	0.47	0.41	0.33	
Conv't'd to annual rate		(0.42)	(0.32)	(0.55)	(0.50)	(0.41)	
1960(4th.)-1961(3rd.): 3/4 year	3.70	1.34	0.56	0.68	0.27	0.52*	
Conv't'd to annual rate			(0.49)	(0.62)	(0.19)	(0.44)	
				Arith. Avg		0.50	0.69
1958-1959 (2nd.)	15.1	0.89	0.41	0.52	1.18	0.74	
1959-1960 (2nd.)	26.7	0.56	0.47	0.66	0.50	0.53	
1960-1961 (2nd.)	—	0.69	0.28	0.23	0.30	0.38	
				Pooled Avg		0.55	
				Arith. Avg		0.55	0.60

*Ages 4-7 only

four were used to provide continuity in the survival estimates. The survival ratios for the period from third quarter, 1959 to fourth quarter, 1960 represent therefore, 5/4 of a year, and the ratios were converted to the corresponding annual rates. Similar adjustments were made in the 1960-61 period, which represented 3/4 of a year, to indicate annual rates.

The average annual survival rate, estimated from data of the third and fourth quarters, was 0.50, corresponding to an instantaneous total mortality rate, Z, of 0.69; the survival and mortality rate estimates for quarter two are very similar, 0.55 and 0.60, respectively. The somewhat higher estimate of survival of the period 1958-59 in both seasons results almost entirely from the apparently higher survival rate of the 1955 year class from age 2 to 3 (0.90 and 0.89). This could be due to a number of causes, e.g., less complete recruitment of 3-year-olds in 1958, inaccurate estimates of abundance index or numbers landed, or erroneous age assessment, but the data do not allow us to distinguish among them.

5. Comparisons between Subareas R and S, Sampling Area 41

For landings of haddock caught by hook and line, Needler (1930) reported similar length compositions, but greater average length-at-age off Campobello (Subarea S) than off Digby (Subarea R). To examine this aspect with current data, we have computed length and age frequencies, and mean age per 2 - cm length intervals for three periods in which sample data were available from both sides of the Bay of Fundy (Subareas R and S).

Most samples from Subarea S, the inland side of the Bay, came from around Grand Manan Island, where much of the fishing occurs. Those from Subarea R, the Nova Scotian side, were mainly from off Digby Neck and St. Mary Bay (Fig. 1). All samples are from otter-trawl landings.

The length and age frequencies of landings (Fig. 20), illustrate a marked difference between the two subareas, with R having the greater proportion of smaller and younger haddock. However, estimates of mean age-per-length interval (Table 21) were nearly the same for both subareas, at least for lengths well represented in landings (up to 60 cm). It appears from our data that the growth rate is similar in the two subareas. That smaller, younger fish are landed from the Nova Scotia side of the Bay of Fundy (Subarea R) than from the New Brunswick side (Subarea S) may be related both to differential distribution of stock and to differences in marketability. Our data do not provide a basis for separation of these two factors.

Comparison of Growth, Length, and Age Composition Among Areas

It is of interest to compare the length and age characteristics of haddock landings between the Bay of Fundy and southern Nova Scotia (Sampling Areas 41 and 42 respectively), and among these and adjacent fishing areas of Division 4V-W to the north, and Divisions 5Z and 5Y to the south (see Fig. 1).

Quarterly estimates of mean length at age in landings of the three components of the 4X

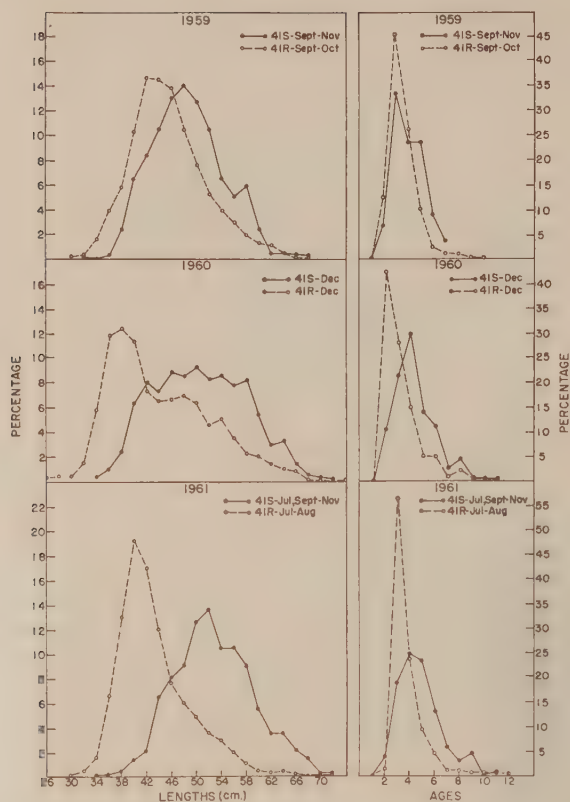


Fig. 20. Comparison of length and age frequency composition of landings from Subareas R and S, Sampling Area 41.

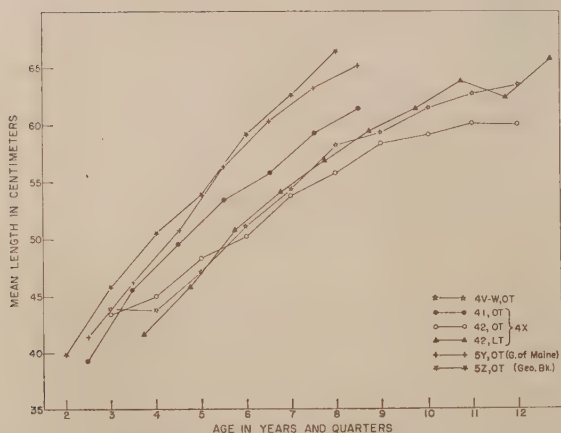


Fig. 21. Comparison of average length-age curves of haddock in landings from various fishing areas.

haddock fishery, which have been obtained in this study, and similar estimates from the otter-trawl landings from Georges Bank (Division 5Z), the Gulf of Maine (Division 5Y), and central Nova Scotia Banks region (Divisions 4V and 4W), have been plotted in Fig. 21. Scales rather than otoliths were used for age assessments in Divisions 5Y and 5Z, but the two methods have been shown to yield similar results for haddock of 5Z up to age 7 (Kohler and Clark, 1958). Furthermore, Jensen and Wise (1962) have presented evidence of the validity of scale age assessments for younger haddock from Georges Bank (Division 5Z). Consequently comparisons among the Divisions are valid at least for younger age groups making up the bulk of the haddock landings. In general, mean length at age is greatest for Georges Bank and Gulf of Maine, intermediate for the Bay of Fundy, and lowest for southern and central Nova Scotia. Mean length at age for haddock in otter trawl landings from central Nova Scotia, and in longline landings from southern Nova Scotia are very similar, but somewhat greater than those for otter trawl landings from southern Nova Scotia, particularly at older ages. The interarea comparisons above yield quite different results than those presented by Needler (1930), who reported similar growth rates for Georges Bank, Digby (Subarea R), Lockeport, and central and eastern Nova Scotia, the highest growth rate for Campobello Is. (Subarea S), and the lowest for Brown's Bank. These discrepancies might be related to differences in sampling and analysis. In particular it should be noted that Needler used scales for all areas and, as noted by Kohler and Clark (1958), haddock scales probably have a tendency to overestimate growth somewhat in southern Nova Scotia waters. In any case the present study is more intensive.

The age frequency curves for otter-trawl landings segregate quite clearly into two groups (Fig. 22). The modal age in landings from Georges Bank (5Z), Gulf of Maine (5Y), and Bay of Fundy (4X, Sampling Area 41) is between 3 and 4 years, with the Bay of Fundy having proportionately more younger fish than the other two. The modal ages for southern (4X, Sampling Area 42), and central (4V-W) Nova Scotia are 6 and 5 years, respectively. Longline landings from southern Nova Scotia have proportionately more older haddock than the others.

The differences in age composition between the Georges Bank-Gulf of Maine and southern-

TABLE 21. Comparison of average age of haddock per length interval in landings from Subareas R and S of Sampling Area 41. Numbers of fish aged are in parentheses.

Length Interval	Sept. - Nov. 1959		Dec. 1960		Jul. - Nov. 1961		Totals	
	41-R	41-S	41-R	41-S	41-R	41-S	41-R	41-S
36	2.4 (10)		2.2 (12)		3.0 (11)	2.0 (6)	2.5 (33)	—
8	2.5 (15)	2.0 (2)	2.3 (18)	2.5 (2)	3.0 (26)	2.0 (6)	2.6 (59)	2.1 (10)
40	2.8 (27)	2.9 (8)	2.1 (27)	2.9 (7)	3.2 (27)	— (11)	2.7 (81)	2.9 (15)
2	3.2 (42)	2.9 (7)	2.7 (18)	2.8 (11)	3.1 (26)	2.3 (8)	3.1 (86)	2.7 (26)
4	3.4 (42)	3.0 (2)	2.7 (16)	3.2 (11)	3.6 (28)	2.7 (12)	3.3 (86)	2.9 (25)
6	3.5 (50)	3.6 (8)	3.3 (22)	3.5 (15)	3.8 (26)	3.2 (13)	3.5 (98)	3.4 (36)
8	3.9 (35)	4.1 (12)	3.5 (22)	4.0 (20)	4.6 (25)	3.1 (13)	4.0 (82)	3.8 (45)
50	3.9 (36)	4.7 (8)	3.5 (33)	4.5 (17)	4.6 (25)	3.8 (19)	3.9 (94)	4.2 (44)
2	4.6 (21)	5.0 (8)	4.3 (26)	4.2 (15)	5.3 (16)	4.5 (13)	4.6 (63)	4.2 (36)
4	4.5 (22)	5.3 (3)	4.3 (20)	4.7 (18)	5.4 (18)	4.4 (16)	4.7 (60)	4.6 (37)
6	4.7 (16)	4.7 (3)	5.3 (15)	5.4 (16)	5.9 (15)	5.1 (12)	5.3 (46)	5.2 (31)
8	6.6 (7)	4.4 (5)	5.0 (11)	5.7 (22)	7.0 (6)	5.1 (14)	6.0 (24)	5.3 (41)
60	6.1 (7)	7.0 (2)	6.4 (8)	7.1 (12)	8.0 (4)	6.4 (9)	6.6 (19)	6.8 (23)
2	6.0 (3)		6.5 (6)	5.5 (11)	7.7 (3)	6.2 (6)	6.7 (12)	5.7 (17)
4			8.0 (5)	7.1 (11)	9.0 (5)	7.3 (8)	8.5 (10)	7.2 (19)
6			8.0 (4)	7.2 (4)	8.5 (2)	7.1 (4)	8.2 (6)	7.1 (8)
8				8.3 (4)	9.0 (1)	8.0 (2)	9.0 (1)	8.2 (6)
70				11.0 (2)		6.0	—	(2)
Average age for length intervals					40-48 cm		3.32 (433)	3.26 (147)
					50-58 "		4.62 (287)	4.68 (189)
					60-68 "		7.27 (48)	6.80 (73)

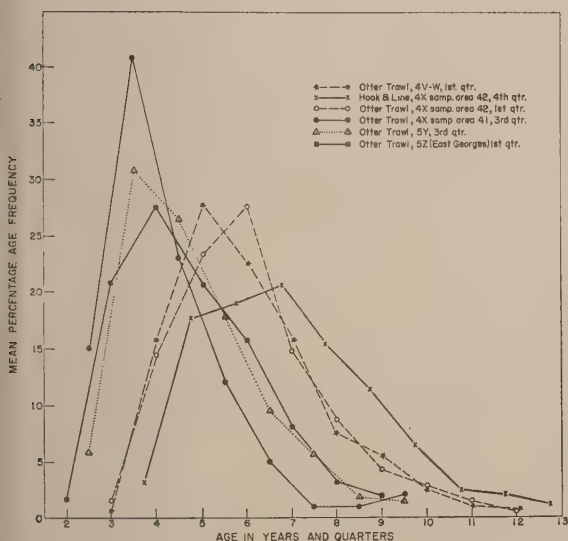


Fig. 22. Age frequencies of haddock in landings from various fishing areas.

central Nova Scotia areas are due mainly to differences in apparent growth rate, because the length compositions are generally similar (Fig. 23). In fact, the higher average age of central Nova Scotia landings occurred in spite of a slightly larger proportion of small fish in the landings. Landings from the Bay of Fundy have the youngest age composition, despite intermediate growth rate, because of the substantially greater proportion of small fish in the landings. The greater proportion of large fish in hook and line landings from southern Nova Scotia is also evident.

While these data on landings are subject to fishing selectivities, the magnitude of differences among some areas is sufficiently large to indicate real differences in the underlying populations. Therefore it seems desirable for some management purposes, to consider haddock in Divisions 5Z, 5Y, and Sampling Area 41 of 4X as a unit stock. The same concept might be applicable to haddock of Sampling Area 42 of 4X, and Division 4V-W.

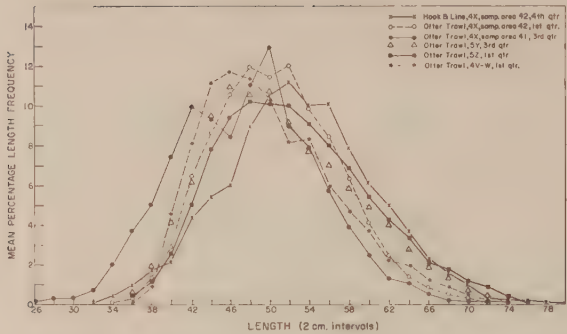


Fig. 23. Length frequencies of haddock in landings from various fishing areas.

In spite of the differences in age and length frequency of haddock landings between fishing areas, similarity in the relative abundance of some year classes suggests that annual brood strength may be controlled by factors common to the entire region. For comparisons among areas, year classes were ranked according to abundance

indices of the three most abundant ages (ages 3-5 for 5Z and 4X, Sampling Area 41; and ages 5-7 for 4X Sampling Area 42). A mean rank was computed for each year class. The rankings are presented below.

Of the four year classes (1952-1955) which are represented in all of the areas, the 1952 year class is consistently of highest rank, and the 1954 year class consistently of second highest rank; the 1955 year class was ranked third in three of the areas and fourth in one area. In otter-trawl landings from 5Z and 4X (Sampling Area 41), the 1956 year class appeared weak, but in otter-trawl landings from Sampling Area 42 of Division 4X the 1956 year class at age 5 appears to be on a par with the 1952 and 1954 year classes.

An analysis of year-class strengths in landings from central Nova Scotia (Division 4W) has not been completed, but it is obvious that the 1952 year class was relatively strong, and predominant in the fishery for several years (unpublished Canadian data).

Year Class	5Z			4X, Area 41			4X, Area 42 OT			4X, Area 42 LT		
	rank at age			rank at age			rank at age			rank at age		
	3	4	5	3	4	5	5	6	7	5	6	7
1949								6	6.0		4	4.0
1950								5	3	4.0	4	3
1951			3				3	1	1	1.7	1	1
1952		6	6			5	6	6	5	5.7	5	5
1953	1	3	5		2	3	1.5	2	2	1.8	2	1
1954	5	5	4	4	4	4	4	4	4	4.0	4	3
1955	3	2	2	2	5	1	1.5	3		2.2	3	
1956	2	4	1	3	1	2	5		5.0			
1957	4	1			1	3				2.0		
1958	6			5								

Summary

In 1956, Canadian and United States scientists initiated a cooperative study of the haddock fishery in Division 4X of ICNAF convention waters. This paper presents estimates of mean length and weight at age, abundance of year classes, and total mortality obtained from analysis of data on landings, fishing effort, and samples of length frequencies and otoliths from haddock in landings for the period 1956-61.

Annual landings varied between 28 and 40 million pounds during the period. The major share of the landings, on the average 17 million pounds per year (8 thousand metric tons) or 51 percent, was taken by otter trawlers fishing off southern Nova Scotia, primarily on Browns Bank in the first half of the year. The otter trawl fishery within the Bay of Fundy took place during the latter half of the year, and produced an average of 8 million pounds (4 thousand metric tons)

annually, or 21 percent of the total. Fishing effort and landings by longliners, which fish mostly off southern Nova Scotia, declined steadily through the period, accounting for about 8 million pounds (4 thousand metric tons) annually, or 28 percent of the average total annual landings.

The 6 year old fish contributed the maximum numbers of haddock to otter-trawl landings from southern Nova Scotia, and had attained an average length of 50 cm and weight of 2.5 pounds (1.1 kg) at this age. At age 10 the fish average 60 cm or 4 pounds (1.8 kg). Less than 3 percent of the fish in the landings were older than 10 years. Longline landings contained proportionately more larger and older fish than did the otter trawl landings. This is due to the different size selectivities of the two kinds of gear. The average annual survival rate of the southern Nova Scotia stocks was estimated to be 48 percent, which is equivalent to a total annual instantaneous mortality rate of about 0.7.

In landings from the Bay of Fundy area, the age of maximum frequency was 3 years, at which time the fish averaged 46 cm or 1.8 pounds (0.8 kg). There were very few fish over age 6 in the landings, at which age they averaged 56 cm or 3.3 pounds (1.5 kg). The average survival rate was estimated to be 50 percent, corresponding to an instantaneous mortality rate of about 0.7.

Thus, there was found to be a striking contrast between length at age and age composition of haddock in landings from the Bay of Fundy and southern Nova Scotia fishery grounds, the former area having much faster growing and younger fish. Making the reasonable assumption that fish in the landings are representative of the stocks beyond the age of full recruitment, the data provides evidence of autonomy of adult populations in the two areas.

Apparent growth rate and age composition of haddock in landings were compared among Division 4X, Division 5Z (Georges Bank) to the South, and Division 4V and 4W to the North. The age structure of stocks in the Bay of Fundy

area was very similar to that of 5Z, although the growth rate in 5Z was somewhat greater. Growth rate and age composition in Division 4V-W was quite similar to that of the southern Nova Scotia area.

In spite of the observed differences in growth and age compositions, the relative abundance of year classes was found to be quite similar in all Divisions, indicating that perhaps some general, common condition controls success of year classes, or that the stocks of the various divisions are mixing at the egg, larval or pre-recruit stages. The 1952 year class was the most abundant of those included in the data.

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Classroom

Ideas

Biology

Age of Fish from Their Scales

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It is very important to a research biologist, studying the biology and life history of a group of fish, that he be able to determine the age of these fish. Many people are familiar with the fact that the ages of trees often can be determined by counting the rings, or annual growth marks, in a cross section of the tree. It is perhaps not so well known that the age of many fishes also can be determined by counting the annual growth marks on their scales. During the warm summer months, fish actively feed and grow, and their scales also grow. Then, as winter approaches and the water begins to get colder, the fish become less active. They do not eat as much and, consequently, they do not grow as much. The growth of their scales also is reduced during these colder periods; hence, the number of reduced growth marks on the scale will tell how many years the fish has lived.

Figure 1, for example, shows a scale from a sockeye salmon. The lines, or rings, on this scale are called circuli. When the fish is actively growing during the warmer summer months, the circuli are farther apart. Then, as growth slows down, the circuli get closer and closer together. This area of close circuli, or slow growth, is called an annulus.

The life history of sockeye salmon is such that this fish spends the first year, and possibly the second, in a lake before it migrates to the ocean. The circuli formed while the fish lives in the lake are called the nuclear, or lacustrine, zone. The circuli formed after the fish enters the ocean are labeled the marine zone. Conditions for growth are not as good in the lake as they are in the ocean and, consequently, the circuli in the nuclear zone are much closer together than they are in the marine zone.

In determining the age of the fish from which the scale in Figure 1 was

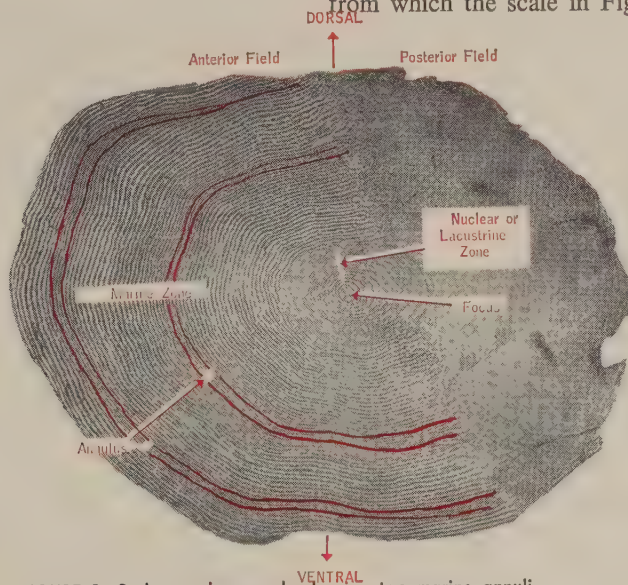


FIGURE 1. Sockeye salmon scale showing two marine annuli.

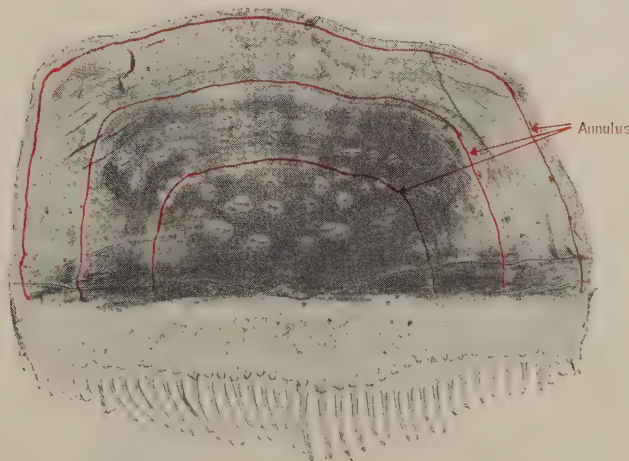


FIGURE 2. Atlantic menhaden scale showing three annuli.

taken, we note that it spent one year in a lake before going to the ocean. In the marine zone of the scale, there is an area of good summer growth followed by an annulus, another area of good summer growth followed by another annulus, and finally an area of good summer growth on the outer edge of the scale. This means that the fish had completed three full years of growth—one in fresh water and two in the ocean—and was in its fourth year at the time this scale was removed.

It is possible also to determine from scale characteristics the age of many fish other than salmon. For example, Figure 2 shows a scale from an Atlantic menhaden. Although there are many differences between this scale and the salmon scale, the formation of an annulus each year makes it possible to tell the age of this fish from its scale

formation. This particular scale has three annual marks, or annuli, and this fish also was in its fourth year of life.

Other, bony structures of fish often can be used to determine their age. A cross section of some of the spines in the fins or of the vertebrae often will show differences between the areas of summer growth and winter growth, making it possible to calculate the age of the fish. This method is used principally for aging sturgeon and catfish. A bone in the ear of fish, called an otolith, also may show these areas of different growth, enabling an observer to determine the age of the fish. Use of the otolith is the principal method by which the age of many of the "flat fish" (fish like the flounder, which live on the bottom of the ocean) is determined. For these fish, scale inspection

is not as satisfactory as these other methods for determining their age.

Unfortunately, it is not possible to tell the age of all fish from their scales or other, bony structures. This is particularly true of fishes which live in more tropical waters and do not counter the marked changes in the seasons experienced by the more northern fishes. In these southern waters, waters remain relatively warm throughout the year, the growth of the fish and its scales continues uninterrupted throughout the year, and there is no area of reduced growth which can be used as an annual mark. In these instances, other methods, such as placing a tag on the fish and measuring the amount the fish grows each year are necessary in order to estimate the age of the fish.

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DRIED UNICELLULAR ALGAE AS FOOD FOR LARVAE OF THE HARD SHELL CLAM, MERCENARIA MERCENARIA

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ABSTRACT

Three species of unicellular algae preserved by drying have been shown to be utilizable as food by larvae of the hard shell clam, Mercenaria mercenaria (Venus mercenaria). The chlorophyte, Dunaliella euchlora, and the chrysophyte, Isochrysis galbana, when freeze-dried gave clam growth and survival comparable to that obtained when these species were fed at similar rates as live algae. Heat-dried samples of the green algae, Scenedesmus obliquus, mass-produced in Japan, also gave good growth and survival of clam larvae. Sulmet (sodium sulfamethazine) increased growth and reduced mortality of clams when used with the dried foods. Agitation of clam cultures proved advantageous when used with dried S. obliquus but gave variable results with the other two species of dried algae. Dried unicellular algae under suitable culture conditions possess desirable physical and nutritive properties for an ideal non-living food for mollusks. If adequate culture techniques are developed, dried algae may find wide application, as in the rearing of juvenile clams and larval oysters.

INTRODUCTION

Larvae of the hard shell clam, Mercenaria mercenaria, can be reared to metamorphosis on a variety of living unicellular algae, but the most rapid growth occurs when these larvae are fed naked flagellates, particularly the chrysophytes, Monochrysis lutheri and Isochrysis galbana (see Davis and Guillard, 1958). The species of algae that are the best foods for larvae are usually difficult to maintain and a considerable investment of time, space, and equipment would be required to provide a sufficient quantity of such foods in live condition for a large hatchery. The desirability of developing a non-living food, that could be stored for long periods, for the hatchery production of shellfish is self-evident. An inexpensive, non-living food available in quantity would not only be extremely practical for routine use in hatcheries, but would also assure a uniform and reliable source of food for many experimental studies on bivalve larvae.

Several attempts have been made to develop foods other than living algal cells for molluscan larvae. Loosanoff (personal communication), as early as 1944, attempted to rear larvae on yeast cells but

obtained unsatisfactory results. Carriker (1956) reared larvae on commercial cereal pabulum flakes with sporadic success.

Chanley and Normandin (1960) tested the value to clam larvae of a wide variety of non-living organic materials, most of which were of little value or had other undesirable characteristics. However, when I. galbana, that had been concentrated and frozen, was resuspended in larval cultures, growth and survival of clam larvae were comparable to those of larvae receiving a live culture of I. galbana. Also, fresh ground preparations of sea lettuce, Ulva lactuca, were found to be an acceptable food for clam larvae. These foods, however, were not entirely satisfactory, in that they produced substantial debris in clam cultures.

Recently our attention has been directed towards use of dried unicellular algae as a molluscan food. It was hypothesized that algal species suitable for molluscan food as living algae may also be suitable when resuspended from a dried preserved preparation. These species might then be mass-produced commercially and dried to produce a uniform preserved molluscan food.

Mass production and drying of unicellular algae have been given considerable attention in recent years (Tamiya, 1957). Production of various species of green algae, Chlorophyceae, for use as a dietary supplement in food for humans and livestock, has thus far received most emphasis. Production of this dried material is now in an advanced stage of development with cost estimates at 17 to 26 cents per pound dry weight (Tamiya, 1957). Little developmental work has been done in producing and drying, in quantity, species of other algal groups, such as the Chrysophyceae. If the chrysophytes are still to be the best foods after freeze-drying, it may be possible to modify existing mass culture techniques to produce a product designed specifically for use in the culture of mollusks.

In this paper we report our results using dried unicellular algae as food for clam larvae, M. mercenaria. We have tested preparations of three algal species, specifically the chlorophytes, Dunaliella euchlora and Scenedesmus obliquus, and the chrysophyte, I. galbana. In this work we have compared growth and survival of clam larvae, when fed the dried algae, with that of clam larvae receiving no supplemental feeding. Also, in the case of D. euchlora and I. galbana, live counterparts of the dried algae were used as controls.

We have also included in this report a description of the methods of culture of larvae that have been found to be of value when using dried algae as food.

METHODS

Except as noted, standard methods for culturing bivalve larvae were used throughout the present series of experiments. The methods of conditioning and spawning adult clams and rearing bivalve larvae in the laboratory have been described in detail by Loosanoff and Davis (1950).

Adult clams were spawned, and fertilized eggs were cultured for 48 hours at concentrations of 30 per ml of sea water. The sea water used was first passed through a Ful-flo orlon filter and then treated with ultraviolet light. After 48 hours the veliger larvae (Fig. 1) were placed in the test culture beakers generally at concentrations of 10 per ml at a temperature of 24 ± 1 C. The sea water in all cultures was



Fig. 1. Clam larvae 2 days after fertilization at initiation of experiments.

changed every second day by retaining larvae on a 250-mesh-per-inch screen. The experimental foods were added daily. After 10 days of feeding, i.e., 12 days after the eggs were fertilized, all cultures were sampled quantitatively. Growth was determined by measuring the length, parallel to the hinge line, of 50 larvae from each sample. Survival was determined by counting the total number of living larvae in the sample and comparing this with the number present at the initiation of the experiment. A uniform culture time of 12 days was practiced so that data from experiment to experiment could be compared directly.

Dried S. obliquus was obtained from the Micro Algae Research Institute of Japan where it was prepared by spray-drying with the use of heat. The dried algal powder was prepared as a suspension in sea water before addition to clam cultures. Two methods of preparation of the algal suspension were tested. One method was by agitating a small amount of the dried material and sea water in a Waring Blendor. The metal parts of the blendor that came in contact with the food suspensions were coated with epoxy resin. Blending for one minute produced a suspension consisting primarily of single intact cells and quadrads of cells. Single cells were 10 to 15 microns long, a size that clam larvae can ingest.

The second method of resuspending the dried S. obliquus produced broken algal cells. It consisted of grinding the dry powder in a ceramic jar mill with Burundum grinding cylinders. Two hours of grinding were sufficient to break almost all of the cells. The resultant particles were mostly 1 to 5 microns in size, although some were as large as 50 microns. The ground powder was then washed through a 325-mesh-per-inch screen with sea water to form the suspension used in feeding. With either method, a fresh suspension was prepared daily for feeding.

The living cultures of D. euchlora and I. galbana were obtained from our mass culture apparatus (Davis and Ukeles, 1961). The dried powders were prepared by concentrating the algal cultures by centrifugation and then lyophilizing the concentrate in a Virtis manifold freeze-drying apparatus. The dried algae was readily resuspended for feeding by adding sea water to the glass lyophilizing tubes and shaking vigorously. A Vibro-Mixer, which mixes by means of a vibrating glass plunger, was also useful in breaking up clumped algal cells that remained in the food suspensions.

To standardize rates of feeding, equal packed cell volumes of each food were used (Davis and Guillard, 1958). Densities were determined by centrifuging each food suspension in a Hopkins tube. After drying, the cells were resuspended in the same volume of water as was present before drying, so that the original packed cell volume could be used in calculating comparable feeding rates of dried and living I. galbana and D. euchlora.

In addition to our usual method of culturing larvae in standing cultures several methods of agitating the cultures were used to determine whether agitation was necessary to keep the dried algae from settling. These included (1) an aeration device in which compressed air was finely dispersed through a "stone" and emitted at the bottom of

the culture container; (2) the turbidity apparatus, described by Davis (1960), in which closed containers of larvae were rotated on a wheel at a rate of 8-10 rpm; (3) an Eberbach bacteriological shaker on which closed containers of larvae were shaken at a rate of 40 to 60 cycles per minute; and (4) a machine devised to produce simultaneously a horizontal paddling action in some cultures and a vertical plunging action in others (Fig. 2). The paddles and plungers of this machine were made of nontoxic Plexiglas and were operated at a rate of approximately 7 cycles per minute.

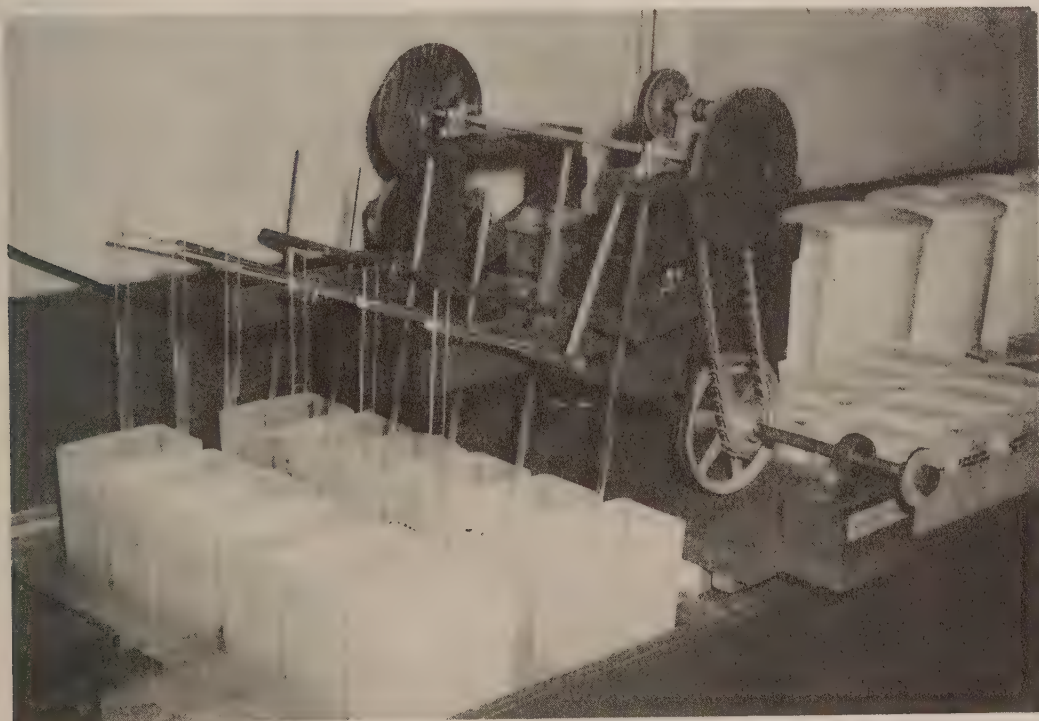


Fig. 2. Agitation machine with which the water in cultures of bivalve larvae is kept in motion by slow action of paddles or plungers. Culture vessels are partly immersed in a constant temperature bath.

Sulmet (sodium sulfamethazine) obtained from the American Cyanamid Company was used, except where noted, as a bacteriostatic agent. Dosage rates were between 50 and 100 parts per million (ppm).

RESULTS

Scenedesmus obliquus

In the first series of experiments stationary cultures were used to compare the rate of growth of clam larvae receiving resuspended intact cells of dried S. obliquus with that of larvae receiving dried S. obliquus with cells broken by grinding (Table 1). Cultures of larvae receiving a mixture of living flagellates and cultures receiving no supplementary food served as controls. In these experiments no bacteriostatic agent was used.

Table 1. Mean lengths at 12 days of clam larvae in non-agitated cultures receiving dried S. obliquus, a mixture of live flagellates and no supplementary food. Mean lengths are averages of duplicate cultures. Feeding rate was 0.01 ml of packed cellular material per liter of larval culture per day.

Culture treatment	Mean length at 12 days (microns)	
	Experiment 1	Experiment 2
<u>S. obliquus</u> (intact cells)	134.20 $\pm$ 2.48 ⁽¹⁾	156.67 $\pm$ 1.73
<u>S. obliquus</u> (ground)	161.50 $\pm$ 2.14	191.05 $\pm$ 1.93
Flagellate mixture (live)	214.10 $\pm$ 1.16	220.27 $\pm$ 2.05
No supplementary food	119.70 $\pm$ 1.20	142.47 $\pm$ 2.19

(1) 95% confidence limits ($\pm 1.98 SE_m$)

Clam larvae ingested the resuspended intact cells of S. obliquus and showed somewhat better growth than the unfed controls. Larvae receiving the broken cells of ground S. obliquus, however, grew much more rapidly than those receiving intact cells, although not as rapidly as larvae receiving the mixture of live flagellates (Table 1). The

relative value of the different foods was the same in two separate experiments, although in the second experiment all cultures, including the unfed controls, grew more rapidly. Additional experiments in which various methods of resuspension of the intact cells were employed gave similar results; in every case the larvae receiving broken cells grew more rapidly than those receiving intact cells. In subsequent experiments, therefore, only ground S. obliquus was used.

In a second series of experiments we tested simultaneously the value of agitation and the use of the bacteriostatic agent, Sulmet, on growth of clam larvae fed ground S. obliquus (Table 2). In two experiments growth of larvae receiving ground S. obliquus in non-agitated cultures was compared to growth of larvae in cultures on a wheel designed to keep materials in suspension. One pair of cultures on the wheel and one pair of non-agitated cultures received 66 ppm of Sulmet with each change of sea water. Similar pairs of agitated and non-agitated cultures were used to determine the rate of growth of larvae receiving ground S. obliquus but no Sulmet. Cultures receiving living algae as food and cultures receiving no supplemental food served as controls.

Of the cultures receiving ground S. obliquus as a food, larvae in the agitated cultures that were Sulmet-treated consistently grew the fastest (Table 2). Although either Sulmet alone or agitation alone did improve growth in S. obliquus-fed clam cultures, growth in these cultures never equalled that in cultures receiving the combined treatments. At 12 days the average size of larvae receiving both the Sulmet treatment and agitation was 179 microns in the first experiment and 187 microns in the second experiment. Although they were significantly smaller than larvae receiving the mixture of live flagellates as food, the larvae did reach setting size and metamorphosed between the 12th and 16th days after fertilization with negligible mortality. The effect of the retarded growth was merely to prolong the larval stage a few days.

In yet another series of experiments the effects of several additional methods of agitation were tested. In addition to our original method using the turbidity wheel, cultures were agitated by means of aeration devices, an Eberbach bacteriological shaker, and paddles or plungers on the machine described in the Methods section (Fig. 2). Although these tests were not extensive enough to detect small differences in efficiency, all but the aeration gave satisfactory results when used with ground S. obliquus and Sulmet. Aeration resulted in variable growth and, in many cases, high mortality. When a timing device was incorporated so that the paddle machine (Fig. 2) stirred the cultures intermittently for three minutes every half hour, growth of the

Table 2. Mean lengths at 12 days of clam larvae in cultures receiving different foods and treatments. Mean lengths are averages of duplicate cultures. Feeding rate was 0.01 ml of packed cellular material per liter of larval culture per day.

Culture treatment	Mean length at 12 days (microns)			
	Experiment 1		Experiment 2	
	Agitated	Non-agitated	Agitated	Non-agitated
<u>S. obliquus</u> (ground) Sulmet	179.38 $\pm$ 1.39 ⁽¹⁾	163.58 $\pm$ 1.74	187.81 $\pm$ 2.21	157.00 $\pm$ 3.27 ⁽²⁾
<u>S. obliquus</u> (ground) No Sulmet	137.38 $\pm$ 1.54 ⁽²⁾	132.58 $\pm$ 2.58 ⁽²⁾	163.78 $\pm$ 2.41	157.40 $\pm$ 2.56 ⁽²⁾
Flagellate mix (live) No Sulmet	197.84 $\pm$ 3.92	197.23 $\pm$ 2.86	218.63 $\pm$ 2.48	--
No food—no Sulmet	125.77 $\pm$ 0.81	129.35 $\pm$ 1.04	125.20 $\pm$ 0.78	119.00 $\pm$ 0.98

(1) 95% confidence limits ($\pm 1.98 \text{ SE}_m$)

(2) Significant mortality—over 20%

S. obliquus-fed larvae was accelerated and there was considerably less coagulation of the suspended food than with any method of constant agitation.

In a single experiment to determine the optimal feeding rate of ground S. obliquus, cultures were agitated and 66 ppm of Sulmet was given with each change of sea water. One pair of cultures was used to test each of the following volumes of packed food per liter of larval culture per day: 0.005 ml, 0.01 ml, 0.02 ml, and 0.03 ml. In general, 0.01 and 0.02 ml of food per day provided the best conditions for growth of clam larvae. Those receiving only 0.005 ml of food per day grew at a somewhat slower rate, and concentrations above 0.02 ml per liter per day produced excessive debris. The larvae given 0.01 ml of packed food per day grew as rapidly as those receiving 0.02 ml of food, until about the 8th day of feeding. From the 8th day to metamorphosis, however, 0.02 ml of food per day was required for optimal growth. A graduated feeding rate in which the concentration of food is gradually increased from 0.01 to 0.02 ml of food per day has since produced uniformly good results.

Dunaliella euchlora

In two experiments the food value to clam larvae of D. euchlora, both as living cells and as a lyophilized product, was compared (Table 3). In these experiments 100 ppm of Sulmet was used throughout and the paddle apparatus (Fig. 2) was used to agitate cultures.

In both trials larvae ingested the dried algae and grew and survived at least as well as larvae fed the living D. euchlora. The mean lengths that larvae attained at 12 days of age when fed the dried D. euchlora (161 to 170 microns) were comparable to growth attained routinely by larvae receiving D. euchlora (Figs. 3 and 4). This growth rate is well below that normally attained by clams when fed other, more desirable species of algae, such as the naked chrysophytes, but, nevertheless, demonstrates that the process of lyophilization, in the case of D. euchlora, did not act to lessen its food value to clam larvae. Also, the lyophilized D. euchlora was mechanically satisfactory in that it was readily resuspended from the dried form as intact single cells and did not produce debris in clam cultures.

In the second experiment (Table 3) clam larvae receiving live D. euchlora failed to grow. This, almost certainly, was the result of the D. euchlora culture becoming heavily bacterized and, thus, toxic to larvae. Larvae receiving live algae were significantly smaller than those receiving no food (Fig. 5), whereas larvae receiving dried D.

Table 3. Mean lengths at 12 days of clam larvae in cultures receiving live and freeze-dried D. euchlora and no supplementary feeding. Mean lengths are averages of duplicate cultures at each treatment.

Culture treatment	Mean length at 12 days (microns)	
	Agitated	Non-agitated
Experiment 1		
Dried <u>D. euchlora</u> 0.01 ml/day	163.60 $\pm$ 3.88 ⁽¹⁾	161.85 $\pm$ 2.09
Live <u>D. euchlora</u> 0.01 ml/day	150.85 $\pm$ 3.05	159.15 $\pm$ 3.41
No food	139.90 $\pm$ 1.78	132.20 $\pm$ 1.04
Experiment 2		
Dried <u>D. euchlora</u> 0.01 ml/day	--	169.65 $\pm$ 1.78
Dried <u>D. euchlora</u> 0.02 ml/day	170.40 $\pm$ 3.13	168.55 $\pm$ 3.94
Dried <u>D. euchlora</u> 0.03 ml/day	--	169.75 $\pm$ 2.12
Live <u>D. euchlora</u> 0.01 ml/day	118.80 $\pm$ 1.21	123.65 $\pm$ 2.18
No food	137.15 $\pm$ 1.92	133.20 $\pm$ 1.18

(1) 95% confidence limit ($\pm 1.98 SE_m$)

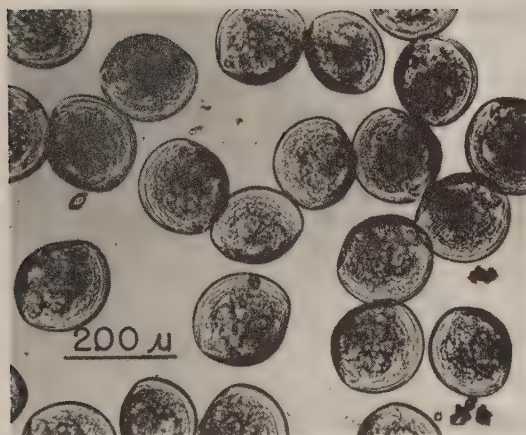


Fig. 3. Larvae receiving lyophilized D. euchlora, 12 days of age.



Fig. 4. Larvae receiving live D. euchlora, 12 days of age.



Fig. 5. Unfed larvae, 12 days of age.

euchlora grew well. Since the algae used in preparing the dried material were harvested before the experiment began, whereas the living algae were harvested throughout the experiment, it seems probable that the culture became contaminated only after the algae for the dried preparation were removed. It is possible, however, that the algal culture was toxic at the time the algal sample was taken for drying and that the lyophilization process in some way acted to detoxify the food.

Agitation of cultures did little to increase growth of clam larvae when used with dried D. euchlora. The mean lengths of 163 and 170 microns attained in agitated cultures in the two experiments were not significantly different than the 161 and 168 microns mean lengths attained in comparable standing water cultures. On the other hand, agitation of cultures was actually somewhat detrimental when used with live D. euchlora. In the second experiment dosage rates of dried algae between 0.01 ml/day and 0.03 ml/day produced no difference in the rate of growth of clam larvae.

Isochrysis galbana

In two experiments larvae receiving the dried I. galbana grew somewhat slower than those receiving live I. galbana but, nevertheless, grew well enough to produce uniform setting with negligible mortality at the end of the 10-day culture period (Table 4). Several cultures of clams receiving the dried algae achieved mean lengths of over 200 microns after 10 days of feeding. This is the rate normally achieved with the best live foods under optimal culture conditions. Larvae ingested the dried particulate material well and took on the brown coloration of I. galbana indicating a direct usage of the dried food. This may be seen as the dark areas of the digestive diverticula of the larvae in Fig. 6.

Agitation of clam cultures fed dried I. galbana produced variable results. In the first experiment cultures receiving dried I. galbana plus agitation reached a mean length of 184 microns, which was significantly larger than the 172 microns mean length of larvae in non-agitated cultures. In the second experiment, however, similar agitation was actually detrimental to larvae receiving the dried food. Larvae reached only 165 microns in these cultures, whereas larvae in non-agitated cultures reached a size of 204 microns. Again, agitation of cultures receiving live food lessened larval growth somewhat in both experiments (Fig. 7). Mortality was negligible in all cultures.

In the second experiment we tested three rates of feeding of the dried I. galbana, from 0.01 to 0.03 ml of packed food volume per day. Clam larvae receiving 0.02 ml per liter of culture per day showed the

Table 4. Mean lengths at 12 days of clam larvae in cultures receiving live and freeze-dried I. galbana and no supplementary feeding. Mean lengths are averages of duplicate cultures at each treatment.

Culture treatment	Mean length at 12 days (microns)	
	Agitated	Non-agitated
Experiment 1		
Dried <u>I. galbana</u> 0.02 ml/day	184.00 $\pm$ 1.68 ⁽¹⁾	172.40 $\pm$ 2.38
Live <u>I. galbana</u> 0.01 ml/day	185.75 $\pm$ 2.10	191.40 $\pm$ 2.31
No food	139.90 $\pm$ 1.78	132.20 $\pm$ 1.04
Experiment 2		
Dried <u>I. galbana</u> 0.01 ml/day	--	177.25 $\pm$ 2.29
Dried <u>I. galbana</u> 0.02 ml/day	165.50 $\pm$ 2.36	204.00 $\pm$ 2.07
Dried <u>I. galbana</u> 0.03 ml/day	--	193.25 $\pm$ 3.85
Live <u>I. galbana</u> 0.01 ml/day	205.05 $\pm$ 2.25	217.85 $\pm$ 2.42
No food	137.15 $\pm$ 1.92	133.20 $\pm$ 1.18

(1) 95% confidence limits ($\pm 1.98 SE_m$)

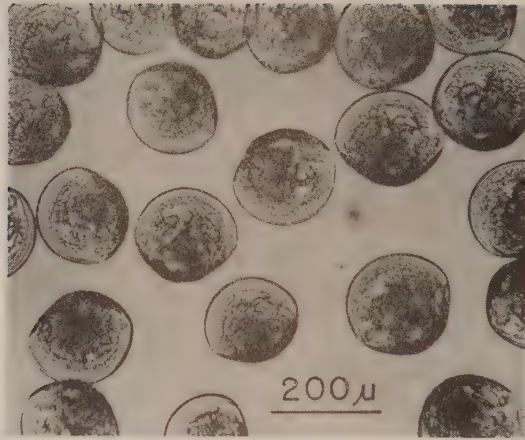


Fig. 6. Larvae receiving lyophilized I. galbana, 12 days of age.

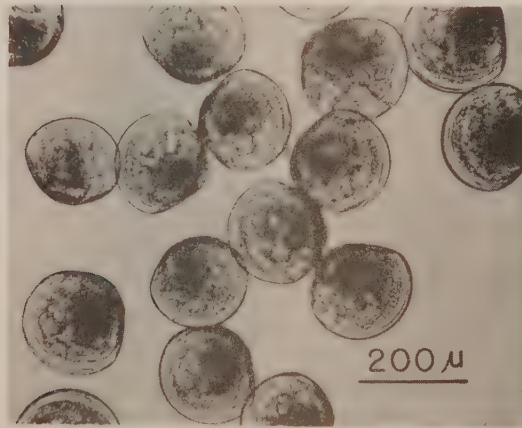


Fig. 7. Larvae receiving live I. galbana, 12 days of age.

most rapid growth (204 microns mean length at 12 days). Growth of the larvae was slower at feeding rates of 0.01 and 0.03 ml per liter per day. This agrees with the results of Davis and Guillard (1958), who tested various concentrations of live I. galbana.

DISCUSSION

It has been shown in this work that dried preparations of the chlorophytes, S. obliquus and D. euchlora, and the chrysophyte, I. galbana, under the proper culture conditions may be used to rear clam larvae to metamorphosis with little difficulty and with negligible mortality. From this type of study it may be argued that the larvae are not feeding on the dried food directly but, rather, are attaining growth by feeding on heavy bacterial populations resulting from the presence of large amounts of organic material. Although the use of bacteria by clam larvae in these studies can not be excluded, at least two lines of evidence suggest that the larvae utilize the dried algae directly. First, the larvae receiving the dried food were observed to ingest the material and to take on the coloration of the food in the digestive diverticulum and digestive gland. This has always been a characteristic typical of growing bivalves fed living algae. Opaque areas can be seen within larvae receiving the dried and live foods (Figs. 3,4,6,7). The second indication of direct utilization is the fact that the rate of growth of clam larvae receiving lyophilized D. euchlora and I. galbana was comparable to that of larvae receiving their live counterparts. D. euchlora, a generally mediocre food for larvae as a live product, was also mediocre as a dried product, while I. galbana, which is a good food, was also good as a dried product. If there had been any large utilization of bacteria, this relationship probably would not have been maintained.

Dried unicellular algae possess desirable nutritive and physical properties for foods for bivalve larvae and may, with suitable developmental work, play an important part in the future of commercial shellfish hatcheries. All the unicellular algae tested, when resuspended as discrete or unbroken cells, tended to remain so and did not clump to form unwanted debris. Although in previous studies (Chanley and Normandin, 1960) many types of organic materials were nutritious to clams, nearly all included a great deal of unusable material which accumulated as debris in the cultures. This hindered the rearing of larvae and absolutely prevented the use of such materials as food for juvenile clams. The accumulation of debris that takes place during the free-swimming larval period can not be completely separated from the larvae by screening. Furthermore, the bottom-dwelling juvenile stages present a particular problem since they are in close contact with the debris and normal functions are impaired. Apparently the largely cellular nature of the dried algae acts to reduce clumping. This was observed in experiments with S. obliquus where ground cells produced considerable debris but unbroken cells produced practically no debris. Clumping and settling of organic material also encourage microbial growth that may be detrimental to growth and

survival of clams. The use of Sulmet has been helpful in minimizing the effect of bacteria, but additional work is needed to develop other, more effective agents.

Certain precautions must be taken in the preparation of a dried unicellular alga if it is to be used successfully as a food for larval mollusks. Many mass-produced and dried algae are either reared or dried in contact with various metals. This may make these foods unsuitable since metallic ions have repeatedly been shown to be highly toxic to larvae in this laboratory. There is also the possibility of introducing toxic metals by various methods of resuspending the dried material for feeding. The Waring Blendor, which very nicely resuspended S. obliquus as single cells, introduced toxic ions when the metal impeller blade and housing were not first coated with plastic. The use of a Vibro-Mixer with glass parts in contact with the food suspension avoided this difficulty by resuspending the dried algae without danger of introducing harmful metallic ions.

The development of a non-living food for the highly sensitive larvae of the American oyster, Crassostrea virginica, presents a major problem at this time. In preliminary experiments lyophilized preparations of I. galbana, which is an excellent food in the live state for larval oysters, gave little or no growth of oyster larvae. At very low feeding rates some growth of oyster larvae has been attained, but as the feeding rate is increased, growth is correspondingly decreased. This indicates the existence of conditions adverse to oyster larvae rather than any inability on their part to ingest and utilize the dried algae.

In summary, dried cells of three species of unicellular algae appear to be directly nutritive to clam larvae and, under suitable conditions, possess the physical properties desirable in artificial foods for the culture of shellfish. Problems to be overcome include the development of methods of culture of juvenile clams and larval oysters with these foods.

ACKNOWLEDGMENTS

The authors wish to express appreciation to Dr. Victor L. Loosanoff for obtaining the dried S. obliquus from the Micro Algae Research Institute, Kunitachi, Tokyo, Japan and also to Dr. Hiroshi Nakamura for preparing the material. Appreciation is also extended to Mr. Joseph F. Lucash for construction of the apparatus in Fig. 2, to Mr. Manton L. Botsford for photographs, to Mr. Russell E. Clark for laboratory assistance in the initial phases of this work, and to Mr. Harry C. Davis for general assistance.

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Preservation of Trout and Salmon Erythrocytes for Blood Typing by Freezing with Dimethyl Sulphoxide

IN the expanding field of immunogenetics several laboratories are studying blood types of fishes¹. In our laboratory we are engaged in investigations of the blood types of Pacific salmon². As part of this programme freezing methods have been examined as a means of long-term red blood cell preservation.

Numerous recent publications have reported the successful freezing and recovering of erythrocytes. Most of the work has been done with mammalian erythrocytes, which, unlike fish erythrocytes, are non-nucleated. Two basic approaches have been used: slow freezing, usually using glycerol as a protective additive, and ultra-rapid freezing with several different techniques and additives. Human erythrocytes have been fast-frozen and stored in liquid nitrogen for periods of up to 2.5 years without significant antigenic change^{3,4}. Cushing, Ridgway and Durall⁵ in 1957 slow-froze and recovered red cells from the shiner, seaperch, albacore, goosefish, and three species of salmon using glycerol as a protective additive.

We have studied several methods of low-temperature preservation of salmonid red cells. Several compounds which have been successfully used as protective additives in frozen preservation of mammalian red cells have been used in attempts to protect salmon red cells from freeze-thaw damage. These include dextrose, lactose, sucrose, maltose, polyvinylpyrrolidone (PVP), and glycerol. None has satisfactorily protected fish erythrocytes for use in blood typing. For example, salmonid red cells frozen in liquid nitrogen (-196°C) using dextrose as the protective additive have been thawed with as much as 89 per cent recovery of unhemolysed cells, but the rate of hemolysis after thawing was so rapid that the erythrocytes were usable for blood typing for only 1-2 h. Red cells from immature red salmon (*Oncorhynchus nerka*) have been frozen in liquid nitrogen using PVP as protective additive and recovered with almost no hemolysis after storage in liquid nitrogen for as long as 1 year. However, PVP did not adequately protect red cells from adult red or chinook (*O. tshawytscha*) salmon against freeze-thaw lysis. Glycerol at a final concentration of 20 per cent by volume provided protection for red cells from all species tested, but was difficult to remove from the cells without resultant extensive hemolysis. We have attempted to wash glycerol

from frozen-thawed salmon erythrocytes using solutions with graded dilutions of glycerol, and also have dialysed glycerol-frozen salmon red cells against 1 per cent saline or CDS solution (dextrose, 2.05 g; trisodium citrate, 0.80 g; sodium chloride, 0.40 g; water to 100 ml.). Neither procedure was satisfactory as haemolysis was extensive on washing cells in solutions with progressive 2.5 per cent reductions in glycerol concentration, and few intact red cells were recovered after dialysis.

Dimethyl sulphoxide provided better protection against freezing damage to salmonid fish erythrocytes than any other additive studied. This substance was used by Lovelock and Bishop⁶ to freeze human and bovine red blood cells and bull sperm, and by others⁷⁻¹² to freeze and recover mammalian bone marrow, tissue, and peripheral blood cells. Using this compound with salmonid red cells we have obtained red cell recoveries after freezing and thawing of up to 99 per cent. In Table 1 are presented the results of one experiment comparing percentage of haemolysis of rainbow trout erythrocytes frozen using either glycerol or dimethyl sulphoxide (in CDS).

In other experiments with a variety of freeze-thaw conditions and additive concentrations, per cent of unhaemolysed salmonid erythrocytes recovered after freezing using dimethyl sulphoxide was invariably greater than that obtained using glycerol. Moreover, dimethyl sulphoxide can be readily washed from salmon red cells without appreciable haemolysis occurring, provided the dimethyl sulphoxide concentration is progressively reduced through 3 or 4 steps.

Table 1. PROTECTION PROVIDED BY DIMETHYL SULPHOXIDE OR GLYCEROL SOLUTIONS AGAINST FREEZING HAEMOLYSIS OF RAINBOW TROUT ERYTHROCYTES

Additive	Percentage of haemolysis after freezing			
	15 min pre-freezing		60 min pre-freezing	
	incubation with additive		incubation with additive	
	Mean	Range	Mean	Range
Dimethyl sulphoxide (12.5 per cent)	3	(2-3)	2	(1-2)
Glycerol (20 per cent)	17	(11-21)	8	(7-9)

Three samples from the same blood pool (3 fish) were tested in each case. Freezing was at -35°C ; thawing was in a 40°C water bath. Percentage of haemolysis was calculated immediately after thawing from suspensions of red cells in 12.5 per cent dimethyl sulphoxide or 20 per cent glycerol.

Table 2. HAEMOLYSIS OF RAINBOW TROUT ERYTHROCYTES FROZEN AND THAWED IN CITRATE-DEXTROSE-SODIUM CHLORIDE-DIMETHYL SULPHOXIDE SOLUTIONS

Percentage of dimethyl sulphoxide	Percentage of haemolysis	
	Mean	Range
0	100	
5	66	(62-72)
9	9	(6-12)
10	4	(2-5)
12.5	3	(2-5)
15	3	(1-5)
17	24	(18-34)

Three samples of blood pooled from seven fish were tested at each concentration. Freezing was at -35°C ; thawing was in a 40°C water bath.

Suspensions of CDS-blood containing 9-15 per cent by volume final concentrations of dimethyl sulphoxide provided good protection against freezing damage. In Table 2 data are presented showing the haemolysis of rainbow trout (*Salmo gairdneri*) erythrocytes frozen in glass tubes at -35°C using dimethyl sulphoxide concentrations from 0 to 17 per cent. In this experiment erythrocyte recoveries from 19 blood samples frozen in 9-15 per cent dimethyl sulphoxide solutions ranged from 88 to 99 per cent, with a mean of 94 per cent. However, extensive haemolysis resulted from continued storage at -35°C ; samples stored for one month at this temperature were completely haemolysed. Other samples were frozen at -35°C or -79°C and then stored in liquid nitrogen for periods as long as 5 months without significant haemolysis.

Erythrocytes from rainbow trout, steelhead trout (*S. gairdneri*), red salmon, chinook salmon, pink salmon (*O. gorbuscha*), chum salmon (*O. keta*), and Pacific halibut (*Hippoglossus stenolepis*) have been slow- and/or fast-frozen using dimethyl sulphoxide, and good red cell recoveries consistently obtained. Although the best cell recoveries occurred using an initial freezing temperature of -35°C , not all salmonid erythrocytes can be successfully frozen at this temperature. For example, red cells from a population of hatchery red salmon were extremely fragile after being frozen at -35°C , using dimethyl sulphoxide, but were stable and resistant to physical stress (1,000g) after being frozen directly in liquid nitrogen. Recoveries of greater than 70 per cent have consistently been obtained from all salmonid species tested using 1 volume of 25 per cent dimethyl sulphoxide in CDS to 1 volume blood-CDS suspension, with aluminium foil packets as freezing containers and liquid nitrogen as the freezing agent. Unbuffered dimethyl sulphoxide solutions are acidic (pH about 5.6) and unsuitable for preservation of trout and salmon erythrocytes. The slightly alkaline solution of dimethyl sulphoxide in CDS was found to be optimal for preservation of these cells.

In a number of tests, using rainbow trout iso-immune, carp immune, or rabbit immune antisera, the antigenic specificities of fish red blood cells frozen with dimethyl sulphoxide have been unchanged from those of unfrozen controls. Salmonid red cells were agglutinable when suspended in 12.5 per cent dimethyl sulphoxide solutions, but most of the blood typing has been performed after removal of the additive.

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OXYGEN UPTAKE OF DEVELOPING EGGS AND LARVAE OF THE HERRING (*CLUPEA HARENGUS*)

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(Text-figs. 1-7)

The work described in this paper is part of a more general programme of study on the physiology of the egg and the physiology and behaviour of the larvae of herring (*Clupea harengus* L.). The wide variation in the size of the eggs produced by different herring races results in great differences in the size of the newly hatched larvae and the time during which they can survive on their yolk supply (Blaxter & Hempel, 1963). A better understanding of the metabolic commitments of larvae in relation to their origin and size, to their age, and to temperature and salinity is required in order to appreciate the effects of variations in egg size and the mechanisms of physiological regulation. Recent studies on osmoregulation (Holliday & Blaxter, 1960) and temperature tolerance (Blaxter, 1960) have been made on herring larvae, but little else is known of their physiology, except what has been deduced from anatomical work (see review by Blaxter & Holliday, 1963).

Marshall, Nicholls & Orr (1937) compared the oxygen uptake of groups of herring larvae from the Scottish west coast kept in light and darkness, and Volodin (1956) that of various stages in the development of Baltic herring, correlating peaks of uptake with specific events in the embryology of the fish.

MATERIALS AND METHODS

Two main groups of larvae were used and two types of respirometer. After a number of preliminary trials using a Warburg apparatus on larvae obtained from the Scottish west and east coasts, the main studies were as follows:

(1) On larvae from Norwegian spring spawners caught in March 1962, near Bergen. These herring produce large eggs (dry weight about 0.35 mg)

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with resulting large larvae on hatching. The oxygen uptake of these larvae was measured by means of Warburg manometry at the Havforskninginstitut, Bergen.

(2) On eggs and larvae from Baltic spring spawners caught near Kiel in May 1962. These spawners produce much smaller eggs (dry weight about 0.10 mg) and larvae. The eggs and larvae were transported by air to Aberdeen and studied there by use of a reference diver technique (Scholander, Claff & Sveinsson, 1952) and by Warburg manometry.

The reference diver with a sensitivity of about $\pm 7 \times 10^{-4}$ μ l. permitted minute by minute observation on the oxygen uptake of a single organism in relation to its behaviour, but under confined conditions. The Warburg with a much lower sensitivity (± 0.5 μ l.) was used on groups of organisms over a longer period in a somewhat less restricted environment, but no continuous observations on activity could be made. The two methods are complementary and have been found to give results in close agreement (Lasker & Theilacker, 1962).

Ripe gonads were obtained from spawning fish and transported to the laboratory in vacuum jars at a temperature of about 4° C (see Blaxter, 1962). Here the eggs were fertilized under controlled conditions, subsequently sticking naturally to glass plates. These plates were kept at a constant temperature in tanks of running sea water or in jars containing water of different salinities.

The main temperatures used were 8, 11 and 14° C; survival of eggs and larvae tended to be poor at 5° C. Salinities ranged from 5 to 50‰, low salinities being made up by adding distilled water to sea water (34‰) and high salinities usually by adding NaCl to sea water. In Bergen the eggs were fertilized in sea water before transfer to the incubation salinities; in Aberdeen both fertilization and incubation were in the different salinities selected for use throughout the experiment. The time of hatching varied with temperature, ranging from about 21 days at 5° C to 7 days at 14° C. The percentage hatching tended to be low at the extreme salinities; this was especially evident in these Kiel eggs where there was a low rate of fertilization in all but 15‰.

Eggs were prised off the glass plates with a razor blade before being placed in the apparatus. Larvae were transferred by wide-mouthed pipettes. Single organisms were used in the reference diver for 1–8 h in a volume of 20–140 μ l. The Warburg flasks contained 5000 μ l. and usually ten organisms. No great difficulty was experienced in keeping organisms for 24 h in these conditions. Checks were made in the longer experiments so that a correction could be made for occasional mortalities. Normally continuous shaking at a rate of about 50 strokes per minute was employed. In some experiments the flasks were not shaken except for a short time before reading the manometers. From such control experiments it was found that shaking did not cause mortality or have any consistent effect on activity of larvae.

Winberg (1956), Fry (1957) and Brett (1962) drew attention to the factors such as homogeneity of material which need to be controlled in any measurement of oxygen uptake in fish. The experimental material in these experiments was as homogeneous as possible — i.e. same parent fish, although egg size and larval size from one female might vary by a factor of 1.5 (Blaxter & Hempel, 1963). The results are usually expressed in μ l. O₂/mg dry weight/hour (Q_{O_2}).

to eliminate differences in size. In early-stage eggs the dry weight was measured after the chorion had been removed and therefore included both embryo and yolk. In late-stage eggs (just before hatching) and in the larvae the yolk, if present, was dissected off before drying and weighing. The weights were measured after drying to constant weight in an oven at 50° C. In some cases, where it was difficult to weigh single specimens accurately enough (Kiel larval bodies minus yolk weighing less than 0.05 mg), estimates were made from weighing a sample of larvae. Thus the Q_{O_2} s of *larvae*, but not of eggs except the late stages, are based on actively respiring tissue. On occasions the results are given in μ l. O_2 /larva/h over a given time, for instance when comparing 24 h cycles in Norwegian and Kiel larvae.

The factor which was found to override all others in determining oxygen uptake was activity. Therefore, in some experiments, for example when assessing resting metabolism in different salinities or temperatures, the larvae were anaesthetized in a solution of tricaine methane sulphonate at a concentration of 1 in 20,000 (M.S. 222—Sandoz Ltd., Basle). This concentration of anaesthetic was effective in a few minutes and no mortality could be attributed to it either in these experiments or in many others made to test the effects of various anaesthetics. The depth of anaesthesia was not great; when lightly touched the larvae would twitch. This fact, together with the close correspondence between oxygen uptake values in anaesthetized and inactive larvae, suggests there is no sub-basal depression of metabolism with M.S. 222. The larvae recovered a short time after being returned to untreated water.

One of the limitations of the direct Warburg method when used over a number of hours is a tendency for the pH in the flasks to rise. This tendency is less when respiring organisms are present. In preliminary experiments the pH was found to have risen from 8.0 to 8.3 after 6 h with 10 larvae present, and to about 8.7 after 24 h. Routine measurements of pH were not made but there were no signs of a change in oxygen uptake in later experiments which could be attributed to an increase of pH.

RESULTS

THE EFFECTS OF ACTIVITY

Eggs

A number of Q_{O_2} measurements were made on anaesthetized and unanaesthetized Kiel eggs using the reference diver. The activity of unanaesthetized embryos within the egg was observed in the respiratory chamber and assigned to active and inactive categories depending on movements of the tail and the rotation of the embryo as a whole. Measurements were also made in the Warburg apparatus on groups of 20 unanaesthetized eggs immediately before hatching (1 out of 20 hatched) and over the hatching period (12 out of 19 hatched, with 1 dead egg). The results, all at 8° C, are shown in Table 1. The values for the pre-hatch embryos are considerably below im-

mediate post-hatching values. Volodin (1956) and Fry (1957) both suggested that the presence of the chorion inhibited gaseous exchange, the late-stage embryo respiring at a low level in an environment of low oxygen tension. Our results are in agreement with this hypothesis.

TABLE 1. OXYGEN UPTAKE OF KIEL HERRING EMBRYOS IN SEA WATER AT 8°C DURING THE HATCHING PERIOD, RELATED TO THE STATE OF ACTIVITY

	Category	Number hatching	$\dot{Q}_{O_2}$ (mean)	Method
Single eggs	+ Anaesthetic	None	0.94	Reference Diver
	Inactive	None	1.10	Reference Diver
	Active	None	2.00	Reference Diver
Grouped eggs	Just before hatching	1/20	2.07	Warburg
	During hatching	12/19	5.21	Warburg

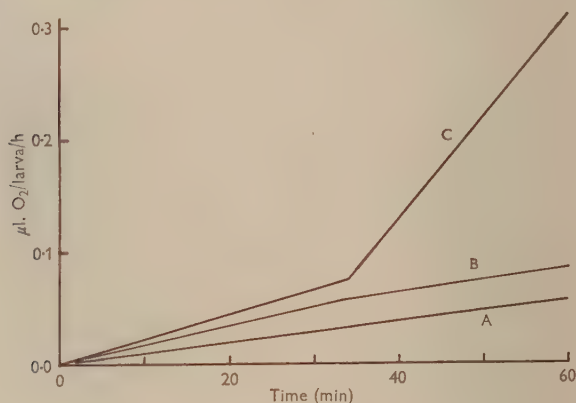


Fig. 1. Effect of change of activity on oxygen uptake after hatching in sea water of single Kiel larvae at 8°C (reference diver). A, Inactive throughout; B, slightly active for 34 min. then inactive; C, slightly active, then very active.

Larvae

Measurements were made in the reference diver on anaesthetized and unanaesthetized Kiel larvae at 8°C shortly after hatching. The activity of the larvae was assigned to four arbitrary categories depending on the frequency of tail beat and general body movement. Values of oxygen uptake were derived first from changes in the activity of one larva during the course of one experiment (Fig. 1) and secondly from the means of different larvae assigned to the various activity stages during the course of several experiments (Table 2).

The lowest category, in which the larvae remained completely inactive throughout the period of observation, gave a $\dot{Q}_{O_2}$ only slightly above the

anaesthetized values. The highest category, in which the larvae swam actively throughout the period of observation, gave Q_{O_2} values nine to ten times the inactive and anaesthetized values. This is very high: Lasker & Theilacker (1962) found that swimming increased oxygen uptake in *Sardinops* larvae by

TABLE 2. THE EFFECTS OF ACTIVITY ON OXYGEN UPTAKE IN THE REFERENCE DIVER

Activity category	Q_{O_2} determinations
+ Anaesthetic	1.87, 1.83, 1.89, 3.03, 2.06, 1.97, 1.37
Inactive	2.27, 2.25
Slightly active	2.90
Active	3.37
Very active	19.00, 19.09

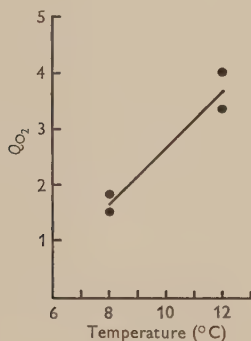


Fig. 2. Effect of temperature on the oxygen uptake of unanaesthetized Kiel eggs (10 eggs per flask) half way from fertilization to hatching in sea water (Warburg).

up to 3.5 times that of the quiescent value, although Ivlev (1960) stated that the oxygen uptake of fry of *Salmo salar* could increase 7–14 times during periods of activity. The nine to ten times difference between the oxygen uptake in inactive and very active larvae is a measure of the 'scope for activity' (Fry, 1947) and is identical in both 35 and 15‰ salinity. These measurements of oxygen uptake did not indicate whether any larvae had accumulated an oxygen debt.

A factor which needs to be taken into account when measuring oxygen uptake in relation to salinity is the difference in buoyancy in different salinities. In low salinities (15‰ and below) the larvae were assigned more often to the 'inactive' category owing to their tendency to sink and remain on the bottom of the respirometer vessel.

Eggs

THE EFFECTS OF TEMPERATURE

The effect of temperature on the developing eggs of Kiel herring (determined in the Warburg apparatus) is shown in Fig. 2. The number of experiments and the temperature range tested was small; the Q_{10} over this range was 3.5.

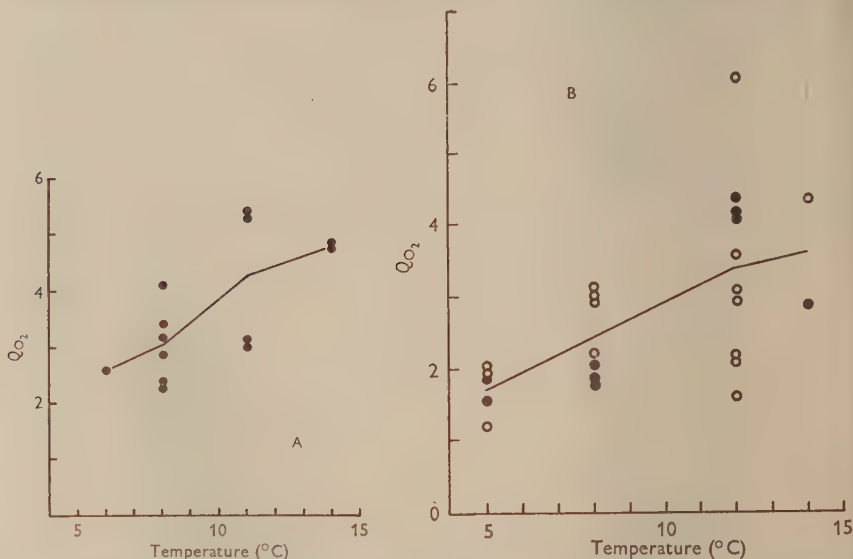


Fig. 3. Effect of temperature on oxygen uptake. A, Of unanaesthetized newly hatched Bergen larvae (Warburg—10 larvae per flask); B, of anaesthetized newly hatched Kiel larvae (reference diver, black circles; and Warburg, open circles—10 larvae per flask).

Larvae

The effect of temperature on oxygen uptake of Bergen and Kiel larvae is shown in Fig. 3. The determinations on Bergen larvae (Fig. 3A) were made on unanaesthetized larvae in the Warburg apparatus; determinations on Kiel larvae were made on anaesthetized larvae in both the Warburg and reference diver. The Q_{10} for both Bergen and Kiel larvae was just above 2, though the level of oxygen uptake was higher in unanaesthetized Bergen larvae. There was considerable scatter in the results, some of which may be accounted for by difference in activity in unanaesthetized larvae and the fact that larvae of mixed age were pooled to obtain some of the determinations.

Constant salinity

THE EFFECTS OF SALINITY

Measurements were made on anaesthetized Kiel eggs and larvae that had been fertilized and incubated in salinities of 5, 15, 35 and 50‰. The eggs

and larvae were matched for size in all these experiments. Table 3 summarizes the results. No difference was found in oxygen uptake of either the eggs or the larvae that could be attributed to the differences in salinities. This result agrees with that obtained by Lasker & Theilacker in *Sardinops* eggs and larvae. It would appear either that oxygen uptake in relation to osmotic and

TABLE 3. OXYGEN UPTAKE OF EGGS AND LARVAE HELD IN DIFFERENT SALINITIES

Rearing salinity . . .		5‰	15‰	35‰	50‰
Eggs (just pre-hatch)	Q_{O_2}				
	1	1.08	1.00	1.00	1.02
	2	1.08	1.01	0.90	1.00
	3	1.05	1.01	0.93	0.99
	Mean	1.07	1.01	0.94	1.00
Larvae (newly hatched)	Q_{O_2}				
	1	2.00	1.89	1.83	1.97
	2	2.00	2.20	1.89	1.96
	3	1.99	1.87	1.89	1.97
	Mean	2.00	1.99	1.87	1.97

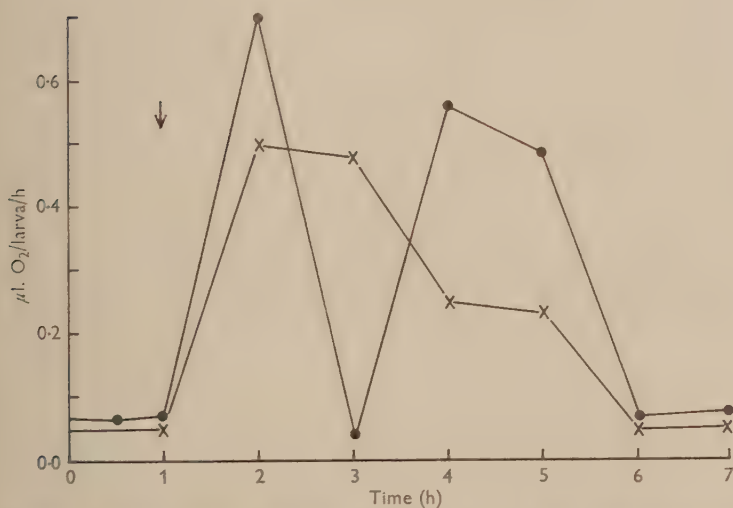


Fig. 4. Effect of abrupt change of salinity on oxygen uptake at 8° C of anaesthetized Kiel eggs $\times - \times$ (just pre-hatch) and larvae $\bullet - \bullet$ (newly hatched) (reference diver). Arrow shows when transfer from 35 to 5‰ took place.

ionic regulatory needs forms a negligible proportion of the standard metabolic rate or (as suggested by Gilchrist, 1956) that an increase in regulatory metabolism is paralleled by a proportional decrease in some other standard metabolic process.

The crustacean, *Artemia salina*, which regulates in a wide range of salinities (Croghan, 1958), also shows no difference in oxygen uptake when kept in

different salinities (Gilchrist, 1956). The careful work of Hickman (1959), however, has shown that the flatfish *Platichthys stellatus* does use more oxygen in saline water than in fresh water. It is possible that differences in tissue sensitivity between species may account for variations in the effects of salinity on oxygen uptake, even in apparently fully adapted fish.

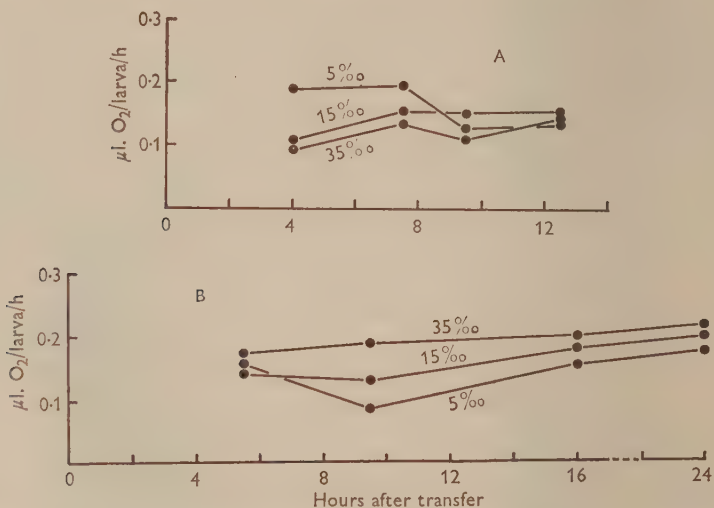


Fig. 5. Effect of abrupt change of salinity on oxygen uptake at 8° C (Warburg, 10 larvae per flask). A, Anaesthetized Bergen larvae 3 days after hatching, observations commencing 4 h after transfer from 35 to 5, 15 and 35‰. B, Unanaesthetized Bergen larvae 3 days after hatching, observations commencing 5½ h after transfer from 35 to 5, 15 and 35‰.

Transfer between salinities

After abrupt transfer between salinities there was, in anaesthetized Kiel and Bergen eggs and larvae, an oscillating uptake of oxygen often up to ten times the pre-transfer value (Figs. 4 and 5A). The decrease in activity due to the buoyancy effect in low salinities probably masks any change in oxygen uptake in unanaesthetized larvae (compare Figs. 5A, B). Disturbances in oxygen uptake were apparent for 6–8 h following transfer. It is during this time that the larvae experience osmotic imbalance before regulating the changing body fluids (Holliday & Blaxter, 1960).

THE EFFECTS OF THE TIME OF DAY

Limited experiments were done in the Warburg apparatus over a period of 24 h on anaesthetized and unanaesthetized Kiel and Bergen larvae. The experiments were made under indoor daylight conditions; the Bergen

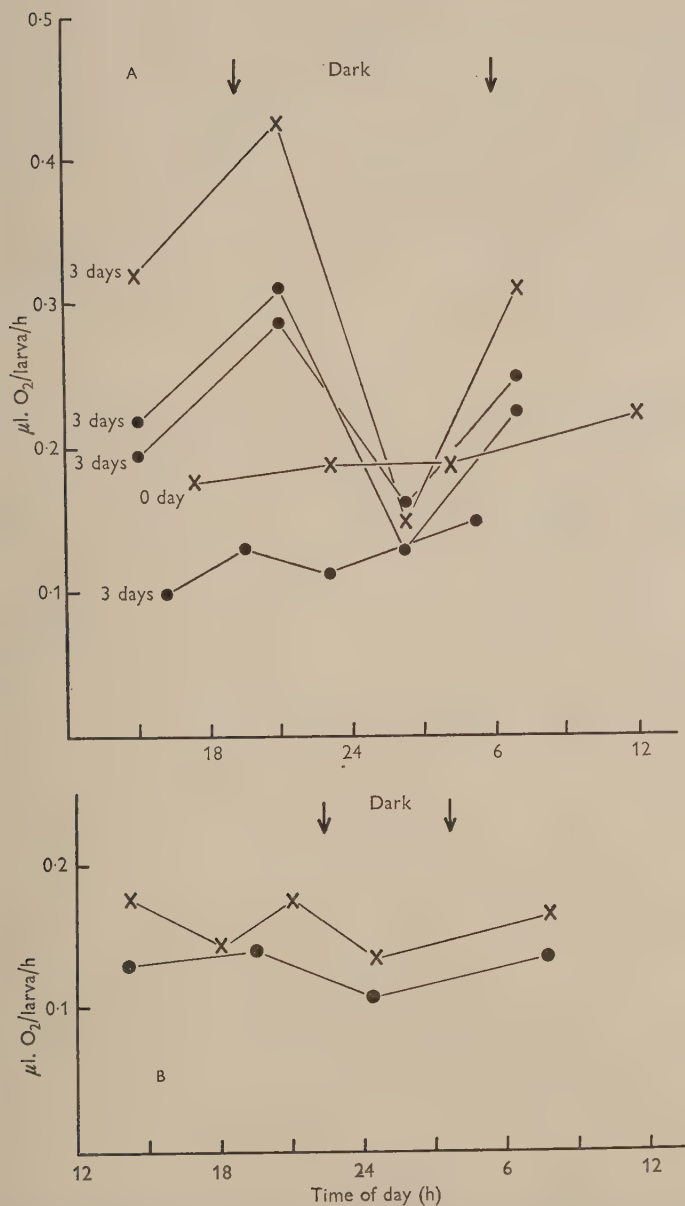


Fig. 6. Effect of time of day on oxygen uptake at 8° C in sea water (Warburg); 10 larvae used per flask; each point refers to mean value for 10 such larvae. Days after hatching on left. A, Bergen larvae: x, not anaesthetized; ●, anaesthetized. B, Kiel larvae: x, not anaesthetized; ●, anaesthetized.

experiments in April (daylight hours in Bergen 06.00–19.30), the Kiel in June (daylight hours in Aberdeen 03.30–22.30).

Oxygen uptake varied greatly but there was little difference between daylight and dark (see Figs. 6A, B); this result is in contrast to that obtained by Marshall *et al.* (1937). However, their experiments differed in design and it is difficult to make comparisons.

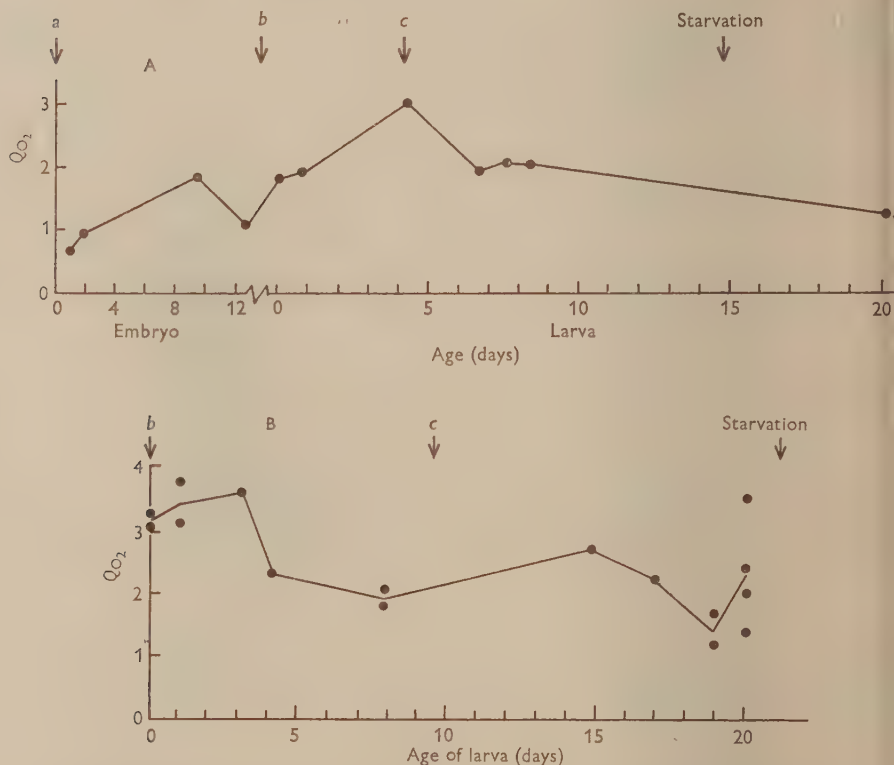


Fig. 7. Effect of age on oxygen uptake at 8° C in sea water. A, Kiel eggs and larvae, anaesthetized (reference diver); B, Bergen larvae, unanaesthetized (Warburg—10 larvae per flask). a, Fertilization; b, hatching; c, end of yolk-sac stage.

THE EFFECTS OF AGE

The effects of age of the developing eggs and larvae on their oxygen uptake are shown in Figs. 7A and B. Results from the Kiel material were obtained from anaesthetized eggs and larvae in the reference diver. The Bergen results were obtained from unanaesthetized larvae in the Warburg apparatus.

Although there was a general increase in Q_{O_2} during the pre-hatching period in the Kiel eggs no allowance could be made, owing to technical difficulties, for the increase in embryonic tissue and the decrease in yolk during development. Thus the Q_{O_2} of actual respiring tissue may not show these changes. The values for the larvae are corrected for yolk and refer to respiring tissue alone. There was a fall in Q_{O_2} after the visible yolk in the yolk sac had been resorbed. The larvae were not fed additionally, and the low Q_{O_2} s of older larvae may be accounted for in part by their starved condition. The Bergen larvae, which were larger and had larger yolk sacs at hatching, showed a reduction in Q_{O_2} well before the end of the yolk sac stage. The Q_{O_2} then fluctuated somewhat but remained at the lower level as they starved.

DISCUSSION

Kiel and Bergen herring larvae differed considerably in size and there was a corresponding difference in oxygen uptake expressed as $\mu\text{l./larva/unit time}$. In general, anaesthetized Kiel larvae had values around $0.10/\mu\text{l./larva/h}$; Bergen larvae had values around $0.25 \mu\text{l./larva/h}$. When expressed as Q_{O_2} of respiring tissue the differences to a large extent disappeared (Kiel 2.3, Bergen 2.5). The oxygen uptake of these two groups of larvae responded in the same way to changes in temperature, salinity and time of day. Age and activity effects were also similar. Some other limited data from spring-spawning herring of the Clyde indicated that the same general responses were found in this group too. For example, oxygen consumption did not differ in larvae reared in salinities from 5 to 55‰.

One of the most interesting results of this work was the extent of the change in oxygen uptake brought about by change in activity. If the level of metabolism is a factor to be considered in relation to larval survival in the sea or in rearing tanks, more information is desired on the activity states and 'scope for activity' of various broods and stocks of larvae. In any hour, after Pacific sardine larvae have started to feed in aquaria, inactive periods averaging about 36 min in aggregate alternate with shorter intervals of active seeking and feeding lasting in aggregate about 24 min (Dr G. Schumann, personal communication, 1963). Larvae may conserve energy in this way.

Comparisons between the reference diver and Warburg techniques showed results of a similar order. A strict analysis would not be valid in any but anaesthetized larvae as it would be difficult to assign categories of activity to Warburg larvae. However, the results for anaesthetized larvae in Fig. 5B, both in the Warburg and reference diver, show that there is a tendency for the Warburg results to be somewhat more variable, which may result from some stimulation of larvae under low anaesthesia due to shaking.

As the duration of the experiments depended on the 'life span' of herring larvae living on their yolk supply, it was not possible to repeat many experiments in order to obtain sufficient material for statistical analysis.

The authors wish to thank Dr G. Hempel (Institut für Hydrobiologie und Fischereiwissenschaft, Hamburg University), who reared the eggs and larvae of Norwegian herring used in these experiments. He also obtained ripe Kiel herring and arranged for their transportation to Aberdeen and took part in the planning and later discussions of the experiments. The assistance of Dr Irmtraut Hempel during the Warburg experiments in Bergen, Norway, was also appreciated.

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SUMMARY

The oxygen uptake of eggs and larvae of Norwegian herring from Bergen (mean unfertilized egg dry weight about 0.35 mg) and of Baltic herring from Kiel (mean unfertilized egg dry weight about 0.10 mg) was measured by a reference diver and a Warburg respirometer. Anaesthetized Kiel larvae had values of about 0.10 μ l./larva/h and Bergen larvae 0.25 μ l./larva/h. When expressed as Q_{O_2} (μ l./mg dry weight/h) the values became Kiel 2.3, Bergen 2.5.

Oxygen uptake of embryos before hatching and of larvae, expressed as Q_{O_2} , was most affected by activity, increasing in very active organisms by five to ten times the resting value of 1–2 μ l./mg dry weight/h. Experiments to test the effects of temperature and salinity were done using anaesthetized larvae in some cases.

Temperature experiments with larvae gave a Q_{10} of about 2, the Q_{O_2} of anaesthetized Kiel larvae ranging from about 2.0 at 5° C to 3.5 at 14° C, and that of unanaesthetized Bergen larvae from 2.5 at 6° C to 5.0 at 14° C.

Eggs and larvae of both races reared in salinities from 5 to 50‰ showed no detectable difference in oxygen uptake. However, abrupt transfer of anaesthetized larvae from one salinity to another caused violent fluctuations (by up to ten times) before adaptation took place. Buoyancy differences appeared to mask differences in oxygen uptake of unanaesthetized larvae in similar transfer experiments.

There was little tendency for oxygen uptake to become reduced during darkness in either Bergen or Kiel larvae.

The effect of age on oxygen uptake (expressed as Q_{O_2}) was not marked, though there tended to be a peak at, and just after, hatching, with a tendency for a fall off during starvation.

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Accumulation of Zinc-65 by Flounder of the Genus *Paralichthys*

DONALD E. HOSS

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ABSTRACT

The amounts of zinc-65 accumulated from water and from food by flounder, *Paralichthys* sp., were measured and compared. When concentration factors were calculated, it was found that flounder concentrated zinc-65 to higher levels from food than from water. The initial rate of accumulation of zinc-65 from water was dependent on the concentration of the radionuclide in the water. Results of experiments reported indicate that the transfer of zinc-65 through the food chain is a more important pathway of accumulation for fish than direct accumulation from water.

INTRODUCTION

Accumulation of zinc-65 by flounder was measured, since this radionuclide is known to be one of the more abundant neutron-induced isotopes released from nuclear reactors and since zinc is known to be an essential element in the metabolism of most animals. Zinc-65 released into the Columbia River by the Hanford Atomic Products Operation was the only reactor effluent found in sufficient abundance beyond the mouth of the river to be of radiological interest (Nelson, 1962). Also, zinc-65 has been reported to account for much of the activity in marine animals taken from the Pacific testing grounds (Lowman, Palumbo, and South, 1957; Donaldson, 1959).

In the laboratory, Chipman, Rice, and Price (1958) followed the accumulation of zinc-65 by fish from seawater and from oral doses of the isotope. In these experiments, rates of uptake and tissue distribution were determined for the croaker, *Micropogon undulatus*, and retention was followed in the pinfish, *Lagodon rhomboides*. The main tissues of accumulation in the croakers were bone, integument, and muscle. Pinfish retained a small per cent of zinc-65 for long periods of time.

Since much of the radioactivity released into rivers and estuaries is often quickly removed from the water by sediments and plankton, the most important source of radionuclides for animals may be plants and animals that have already concentrated the isotope. Davis and Foster (1958) found food to be the main source of radioactivity for fish in the Columbia River.

Laboratory experiments reported in this

paper were designed (1) to follow the accumulation of zinc-65 by flounder, both from seawater and from ingested foods, and (2) to determine what effect the concentration of the isotope in the water had on the rate of accumulation. This study was an attempt to simulate in the laboratory a situation that might occur in nature if a reactor continuously released effluent into an estuary. Young flounder were chosen as experimental animals since they spend their postlarval and juvenile stages in the estuary.

MATERIALS AND METHODS

Three species of flounder, *Paralichthys dentatus*, *P. albigutta*, and *P. lethostigma*, were collected with a meter plankton net (1 mm mesh) as they migrated from the ocean spawning grounds into the estuaries near Beaufort, N. C. When collected, the fish were in the postlarval stage of development. Before being used in the experiments, they were maintained in the laboratory until they reached the juvenile stage. No attempt was made to separate the three species.

The food selected for the experiment was nauplii of the brine shrimp, *Artemia salina*, a crustacean similar in size to zooplankton eaten by juvenile flounder in their natural environment. The nauplii were maintained for 24 hours, prior to being fed to the fish, in seawater containing 0.001 microcurie per ml of zinc-65. At the end of 24 hours, 0.4 g of the nauplii was removed from the water, measured for radioactivity, and fed to the fish. The same procedure was followed in raising the nonactive nauplii, but nonactive water was used.

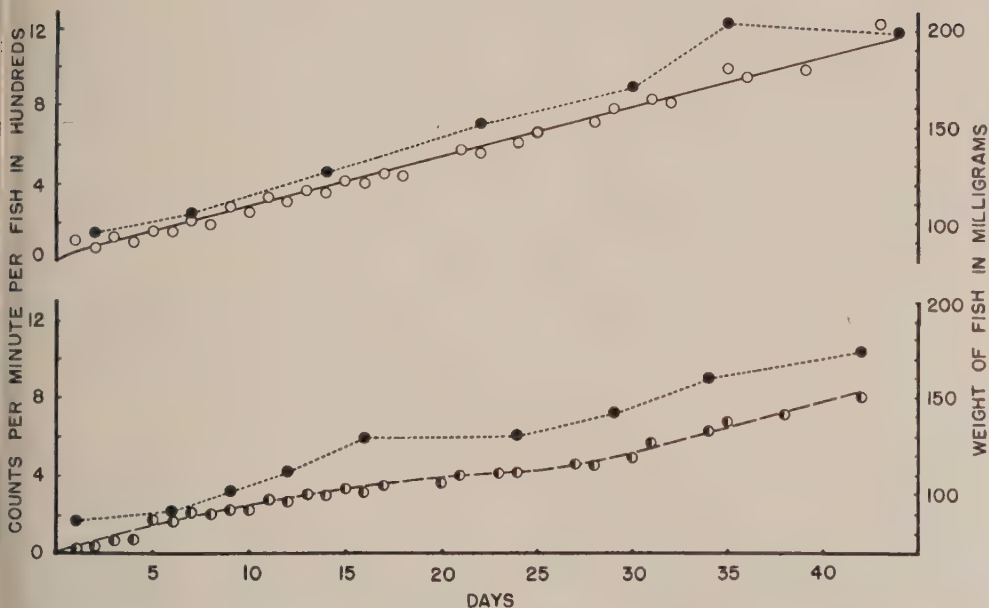


FIGURE 1.—Accumulation of zinc-65 by flounder in relation to change in weight. Closed circles represent average weight of flounder, open circles represent accumulation from water, and half-closed circles accumulation from food.

To compare possible pathways of accumulation, three groups of flounder, each containing 20 fish, were exposed to zinc-65 in the following manner:

(1) One group of fish was placed in a liter of seawater and fed 0.4 g of radioactive brine shrimp every other day. On the alternate days, the fish were returned to clean seawater. The only source of zinc-65 available to these fish was food.

(2) A second group of flounder was placed in a liter of seawater containing the same amount of activity as the water in which the labeled brine shrimp were raised. On alternate days, these fish were placed in nonactive seawater and fed 0.4 g of nonactive brine shrimp nauplii. The only source of zinc-65 for this group of fish was the radioactive water.

(3) The third group of fish was held in water with the above concentration of zinc-65 every other day and on alternate days the fish were transferred to nonactive water and fed active food. Both food and water were possible pathways of accumulation of zinc-65 to this group of fish.

The effect of increasing the amount of zinc-65 in the water on the rate of zinc-65 accumulation by flounder was measured by placing one group of 10 juvenile flounder for 2 weeks in a liter of seawater containing 0.004 microcurie of zinc-65, and by placing a second group of fish for 1 week in a liter of seawater containing 0.008 microcurie of zinc-65. Non-active food was placed in the active water daily so that some accumulation occurred from food as well as water.

Carrier-free zinc-65 with a half-life of 245 days in the chemical form of zinc chloride dissolved in acid was used in amounts which did not increase the measurable zinc concentration when added to water.

Seawater was filtered through cotton to remove particulate material. All experiments were conducted at room temperature (19° to 24° C) and the salinity ranged from 25.2 to 33.7 ppt. The water was changed every day to prevent a buildup of waste products.

The amount of zinc-65 present was measured with a gamma-ray scintillation detector and a well-type 3-inch sodium iodide crystal. Each measurement was corrected for decay

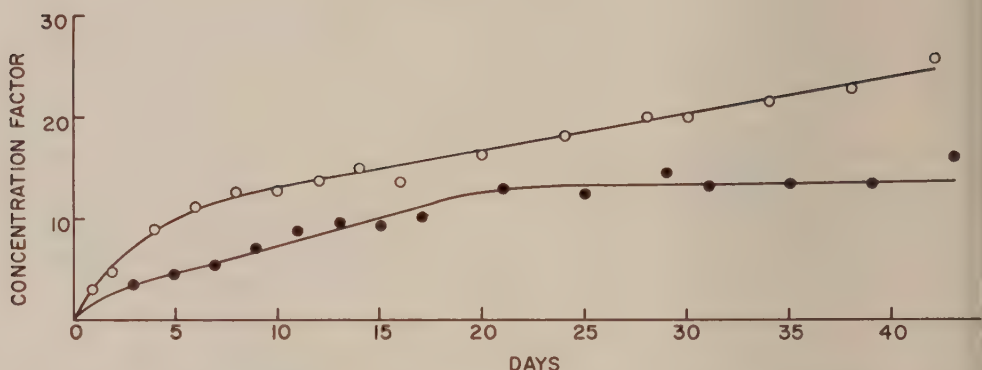


FIGURE 2.—Comparison of concentration of zinc-65 by flounder from food and water. Open circles represent concentration factor over food; closed circles represent concentration factor over water.

and background radiation. After exposure to zinc-65, each fish was removed from the tank, rinsed in nonactive water, and measured for contained activity. Radioactivity in all fish was measured at each sampling time.

ACCUMULATION FROM FOOD AND WATER

Uptake of zinc-65 by flounder from food was compared to the uptake of zinc-65 from water for a period of 44 days. Both groups originally consisted of 20 fish; however, during the experiment six fish died in the group held in radioactive water and four fish died in the group fed radioactive food.

Accumulation of zinc-65 by flounder continued throughout the experiment whether the source of activity was food or water (Figure 1). Variation in the rate of accumulation may be attributed to changes in rates of growth of the fish during the experiment. When the zinc-65 of the fish in active water was based on a concentration factor (counts per minute per gram of fish compared to counts per minute per gram of water), it was found that an apparent equilibrium with the water was reached after 20 days (Figure 2). The apparent equilibrium may be attributed to a "biological dilution" effect caused by increased weight. Baptist and Price (1962) reported that uptake of cesium-137 from seawater based on weight of flounder was reduced during periods of rapid weight increases due to the fish increasing in mass more rapidly than the isotope was accumulated.

The fish obtaining zinc-65 from their food concentrated the isotope over the amount in food throughout the experiment (Figure 2). The concentration factor (counts per minute per gram of fish compared to counts per minute per gram of food) for fish in the accumulation from food experiment was calculated on each fish eating 0.02 g of food containing 177 counts per minute. When the concentration factors for the two groups of fish were compared, it was found that fish obtaining zinc-65 from food contained 1.6 times more zinc-65 than fish obtaining zinc-65 from water. This may appear to contradict the data in Figure 1, until one realizes that the data in Figure 1 were based on the amount of radioactivity per fish, regardless of availability, and that data in Figure 2 were based on concentration factors.

Accumulation by fish having zinc-65 available from both seawater and food was followed for a period of 20 days. Under these conditions, the amount of zinc-65 accumulated was approximately equal to the sum of the amounts accumulated from food and water when these sources of zinc-65 were available individually (Figure 3).

EFFECT OF CONCENTRATION OF ZINC-65 IN WATER ON RATE OF ACCUMULATION

Accumulation of zinc-65 by juvenile flounder from water containing 0.004 and 0.008 microcurie per milliliter was measured over a 14-day period. Values were based on averages

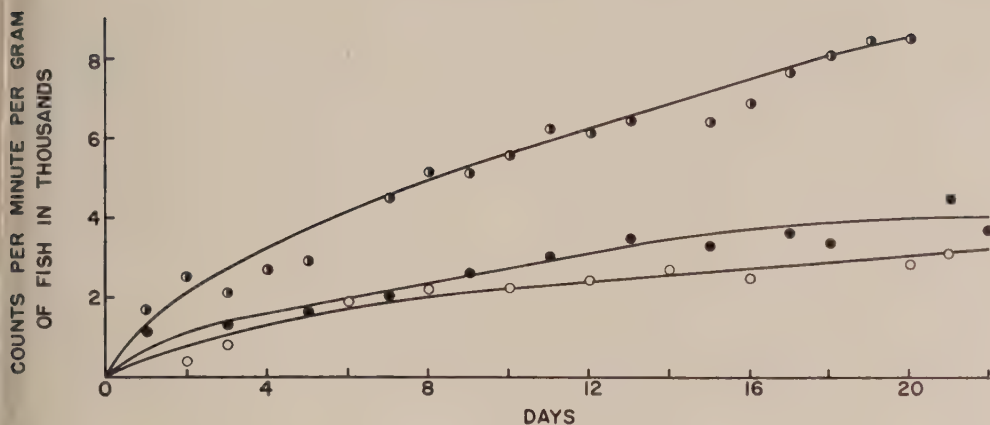


FIGURE 3.—Accumulation of zinc-65 by flounder from food, water, and a combination of both food and water. Half-closed circles represent accumulation from both food and water, closed circles represent accumulation from water, open circles accumulation from food.

of 10 fish taken at each sampling time. Standard deviations and differences between means were calculated to determine if accumulation was significantly different between the two groups at 7 and 14 days.

Doubling the amount of zinc-65 in the water increased the rate of accumulation so that fish in 0.008 microcurie per liter reached the same level of activity as fish in 0.004 microcurie per liter in one-half the time (Figure 4). The mean counts per minute per gram of fish in 0.004 microcurie per liter after 14 days were

not significantly different from the mean counts per minute per gram of fish in 0.008 microcurie per liter after 7 days.

DISCUSSION

In the present experiments, the accumulation of zinc-65 by flounder from food was compared to its accumulation of zinc-65 from water by separating these two pathways in the laboratory. It is relatively easy to follow the accumulation of an isotope from water; however, it is more difficult to follow the accumulation from food. The food must be one that will accumulate and retain the desired isotope; it must be readily available, and it must be an organism that the fish will eat. One method used in the past was to simulate feeding by giving the fish an oral dose or repeated oral doses of an isotope. This has an advantage in that the strength of the dose is easily controlled so that each fish is given the same amount of activity. However, a disadvantage to this method is that the accumulation from a liquid or gelatin dose may not be comparable to the accumulation from a natural food. Schiffman (1961) showed that $\text{Sr}^{90}\text{-Y}^{90}$ was more readily accumulated by trout from gelatin than from natural foods; thus results based on the accumulation of $\text{Sr}^{90}\text{-Y}^{90}$ by fish from gelatin may not show accurately what would occur under natural conditions.

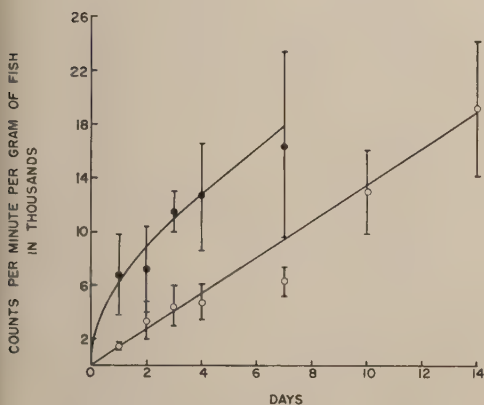


FIGURE 4.—Effect of zinc-65 concentrations in the water on its rate of uptake by flounder. Closed circles represent uptake from water containing 0.008 microcurie per ml, open circles 0.004 microcurie per ml.

Krumholz (1956) pointed out that the element concentrated most by the food organism may not be the element concentrated highest by the consumer organism. By conducting experiments in which a food chain is involved, a better estimation can be made of what would happen if a natural food source were to become polluted with radioactivity.

The amount of activity available to the fish in these experiments was limited by the amount of food. Ideally, the best way to conduct a feeding experiment would be to duplicate the conditions found in nature where food is available at all times. In this experiment, had it been possible to keep the optimum amount of food available to the fish at all times, the difference in concentration factors between the two groups might have been even greater.

Another factor to be considered, when comparing accumulation from food to accumulation from water, is the total amount of radioactive zinc available. Assuming that all of the zinc-65 in the water or food was available, the group of fish accumulating zinc-65 from water was exposed to 22 microcuries during the experiment, while the group of fish accumulating zinc-65 from food was exposed to 0.2 microcurie. At the end of 43 days, the fish accumulating zinc-65 from water contained a total of 0.05 microcurie or 0.2 per cent of the total amount of zinc-65 available, while fish accumulating zinc-65 from food contained a total of 0.04 microcurie or 20 per cent of the total zinc-65 available.

It was found that brine shrimp nauplii accumulated zinc-65 from water at a faster rate than flounder. From this it can be concluded that in the natural environment where all organisms would be exposed to radioactivity, the amount of zinc-65 passing through the food chain to flounder would be greater than that obtained by direct uptake from water. This conclusion is supported by data collected on food chain uptake by freshwater fish (Williams and Pickering, 1961; Ball and Hooper, 1963).

The effect of increasing the environmental concentration of zinc-65 by a factor of two was to increase the initial rate of accumulation of the isotope by the fish. Joyner (1961)

attributed the initial uptake of zinc-65 by brown bullhead, *Ictalurus nebulosus*, mainly to two sorption phenomena: (1) adsorption to mucus on surfaces in contact with the water and (2) absorption by the transfer of zinc ions across semipermeable membranes of the fish. The results of the experiment reported in this paper indicate that doubling the amount of radioactive zinc in the water primarily affects these two pathways of accumulation, since it is the initial rate of accumulation that was affected. The rate of accumulation after 2 days was apparently similar in the two groups of fish.

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UNMANNED BUOYS AND FISHERY OCEANOGRAPHY

by

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UNMANNED BUOYS AND FISHERY OCEANOGRAPHY

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ABSTRACT

Current development, testing, and use of moored unmanned instrumented buoys have largely reflected the requirements of meteorologists and defense oceanographers. Reasons for the neglect of other scientists' needs are suggested. Requirements of fishery oceanographers are reviewed and are shown to be substantially the same as for other groups, excepting measurements of additional properties. Primary mission of unmanned buoys is shown to be the collection of data from the air-sea interface down through the mixed layer and thermocline; each buoy will form part of a network of stations over vast ocean regions. A small, easily handled, inexpensive unit is advocated. Progress toward successful development of such a unit is discussed and the opinion is expressed that such activity deserves increasing attention. Potential benefits to fishery oceanography and the fishing industry from unmanned buoy networks are outlined. Concern is registered that future ocean research, including the operation of buoy networks, will be too costly for fisheries and other interests alone. This fear is minimized by knowledge that man's growing dependence upon the ocean for food and other resources is creating a common need for the same kind of information; therefore, efforts and funds could be pooled to meet this need.

INTRODUCTION

Scheduling of the International Buoy Technology Symposium underlines the growing interest in the development, testing and use of unmanned moored instrument stations. Four groups of scientists are in urgent need of these stations and are certain to benefit from this interest and activity. Most people in this audience would be quick to identify two of the groups, oceanographers concerned with defense and meteorologists. Many would name the academic oceanographers as another of the groups but few would think of scientists engaged in fishery oceanography. It is my purpose to identify the latter and to record that this growing body of scientists, fishery oceanographers, if you like, has the same urgent need for many of the same kinds of time-series observations from fixed unmanned buoys as do other groups.

The scientific study of the sea fisheries of the world is barely more than half a century old. It was born of a need to better use important commercial stocks of fish. It began with life history and migration studies and the analysis of catch-and-effort statistics to determine changes in the condition of particular fisheries in relation to fishing pressure. Later

came the study of variations in fishery yield in relation to changing ocean conditions with a view to their prediction. These studies were not productive in their first years, providing little of predictive value and little in the way of identifying and understanding the ocean processes affecting the distribution and abundance of commercial fishes. During the past 15 years, fortunately, the results have been much more encouraging.

Since I am engaged in tuna research, I like to point to the success of the broad investigations of the relationship between the tunas and their oceanic environment, first in the central Pacific by the U.S. Bureau of Commercial Fisheries, and then by the Inter-American Tropical Tuna Commission and Scripps Institution of Oceanography and, more recently, by the Bureau also, in the eastern Pacific. These investigations have provided the beginning of understanding of some relationships of tunas to their environment. They have resulted in a few successful attempts to predict where and when patterns associated with tuna availability will occur. Besides these things, these broad studies have revealed the complexity of the environmental factors affecting the distribution and abundance of the living resources of the sea. They have pointed out that, if we are to understand and measure environmental dependent changes in availability and abundance, and we must if we are to harvest the living resources of the sea with efficiency, we will require a fundamental knowledge of the interplay of pertinent atmospheric, oceanic and biological processes. Equally important, they have helped cause fishery biology to join with oceanography and meteorology and have given birth to fishery oceanography, defined less than two years ago by the Scientific Committee on Oceanic Research (SCOR) of the International Council of Scientific Unions as "the study of the living resources of the sea using those aspects of oceanography (including biology, physics, chemistry, geology, and meteorology) that affect their abundance, availability and exploitation." You will agree that is a short definition for such a complicated and inclusive field.

Fishery oceanographers, together with other oceanographers and meteorologists, have learned enough about the general scheme of things by which atmosphere, ocean and biosphere are interrelated to appreciate that things are not only infinitely complex but are not in a steady state. One of the most urgent requirements for improving our meagre understanding is the means of obtaining time-series observations of ocean and atmospheric properties at the air-sea interface and down through the thermocline. Unmanned instrumented buoys anchored at strategic locations which are capable of recording observations automatically and continuously offer the best possible means.

REQUIREMENTS

Recognition--Infinitely more has been heard in the United States concerning the needs of defense oceanographers and meteorologists for unmanned instrumented buoys than there has been of the requirements of fishery oceanographers or academic oceanographers. An obvious reason for this situation is heavy pressure for predictions. Meteorology has long been beset by the need for predictions, and meteorologists are quick to realize that ocean buoys can provide them with another means of improving, and extending weather forecasting. Also, meteorologists can no longer be disinterested in the ocean, for positive feed-back to the atmosphere from anomalous oceanic conditions may have to be

taken into account before accurate extended weather forecasts can be issued. Modern military systems no longer can be based on the average state of the sea. Operating naval forces are demanding up-to-the-minute environmental intelligence to estimate such things as sound propagation and thermocline topography. As a result, defense oceanographers now experience the same need for forecasts as meteorologists have long grown accustomed to. They are, therefore, developing means of obtaining synoptic observations from widespread regions of the ocean; thus, networks of unmanned buoys are extremely attractive.

Scientists engaged in fishery research and the academic oceanographers have generally been slow to register and, in some cases, recognize their need for time-series data from the ocean environment. There has been, with few exceptions, no strong voice from either group concerning the need for unmanned buoy networks. Many academic oceanographers are horrified at the amount of data which might flow from such a system. They tend to feel that basic understanding must precede forecasting but, of course, they are not subjected to pressure for the latter. Small as it is, though, there is a growing number who concede that buoy observations could well advance understanding by providing academic oceanographers with a great opportunity for basic research.

Scientists in fishery oceanography are waking to the opportunities that unmanned buoys could provide. The interest is greatest among those concerned with wide-ranging pelagic fishes and among teams of researchers representing several disciplines. It is not really surprising that, in the United States, this group's growing interest and need for unmanned instrumented buoys is relatively unknown. The number of scientists is small compared to the number making up the other groups interested in the instrumentation. Another factor is that the commercial fishing industry is but a small part of the national economy. The small voice that we have raised so far has been drowned out by far more vocal groups representing defense and weather. The importance of fisheries and the harvest of the living resources of the sea is gaining attention nationally and internationally, though, and this recognition presents a welcome opportunity to record the requirements of fishery oceanography for instrumented buoys and to compare these requirements with those of the better known potential users.

Properties--A committee established by the 8th Eastern Pacific Oceanic Conference (EPOC) examined problems related to meteorological-oceanographic buoy development. Scientists engaged in fishery oceanography were represented, as were defense oceanographers and meteorologists. A concise account of the committee's findings was reported by Blackburn (1963). His Table 1 summarizes the ways in which the four groups of scientists mentioned here would use moored instrument stations and is reproduced below. With reference to the prescribed maximum depth of 200 meters in the table, the footnote indicates that this will vary with use. However, the primary need for unmanned buoys is to monitor the changing environment at the air-sea interface and down through the mixed layer and the thermocline. This is generally within 200 meters but can be considerably deeper on occasion. In any event, it is the relatively thin upper layer which is of most significance to fisheries and defense and from which time-series data are urgently needed.

Users	Principal purpose	Operating period	Property-sensing levels(m)*	Telemetering necessary?	Station networks necessary?
Meteorologists (civil and military)	Forecasting & understanding	Indef.	+3 to 0	Immediately	Yes
Military oceanographers	Forecasting & understanding	Indef.	+3 to about -200	Immediately	Yes
Fishery oceanographers	Understanding & forecasting	Indef.	+3 to about -200	Eventually	Yes
Academic oceanographers	Understanding	Finite for each problem	·	Depending upon the problem	

*Heights and depths relative to sea surface (+, above; -, below); based on consensus of opinion in each group, but would vary according to user and area of use.

The committee pointed out that each of the first three groups has some of the same usage requirements as another and also found that the same is evident for particular properties. The latter findings are also summarized here. Suitable sensors do not exist for those properties which are underlined.

Meteorologists: Air pressure, air temperature, wind velocity, wind direction, humidity, sea-surface temperature, wave and swell period, wave and swell direction, and possibly solar radiation;

Military oceanographers: Need substantially the same as meteorologists, plus water temperature from 10 to 20 points in upper 200 meters (with depths identified by pressure measurement);

Fishery oceanographers: Need substantially the same as the other two groups, plus the following at several known depths down to 200 meters - salinity, oxygen concentration, visible irradiance*, current velocity, and current direction.

*Refers to measurement of selected spectral irradiance below the sea surface from which the attenuation coefficient (k) is derived.

It would not be surprising to learn soon that meteorologists want certain property measurements assigned above to defense oceanographers and that the latter want some identified with fishery oceanographers. The EPOC committee noted in 1962 that "fishery oceanographers want more kinds of property measurements than any other group, but their need of telemetering is not urgent because they anticipate a learning period before attempting to make systematic forecasts." A few fishery oceanographers already are doing some predicting, so systematic forecasting and the need for telemetering is closer at hand than is realized.

Fishery oceanographers do not presently envision direct measurements of biological properties from unmanned buoy networks maintained for monitoring purposes. Some day, direct measurements of biological properties from automatic buoys may be practical but probably only from buoys used for special research projects. What fishery oceanographers want at this stage and for the foreseeable future, beyond requirements listed for others, are measurements of a few properties directly or indirectly related to biological productivity. These are noted above. Biological activity and productivity are related to oxygen utilization and visible irradiance. Measurements of current direction and velocity are required to understand features of the circulation and such things as the distribution of the biota in time and space.

Design--There are a number of unmanned instrumented buoys under development and testing or, for that matter, in use. Other papers prepared for this symposium describe them but I wish to comment briefly about features of two types as they relate to the requirements of fishery oceanography.

The first unit to come to mind is the Mamos, or Nomad, boat-type station, moored with a slack cable, which is operational. It only satisfies the requirements for surface observations. It has other serious deficiencies as far as fishery oceanography is concerned - it is too costly, too huge, and too difficult to handle. The Mamos buoy is said to cost approximately \$100,000, with annual maintenance estimated at \$10,000 to \$15,000. It is doubtful that fishery-supported investigations will ever have funds to support networks operating such expensive units and it is also doubtful that they could contribute significant amounts for any joint operation with other users. Certainly, it would not be possible to transport and service them with research vessels normally used in fishery oceanography.

Fishery oceanographers and academic oceanographers decided several years ago that their needs could best be satisfied through the development of a suitable and relatively inexpensive unmanned buoy. They have, therefore, watched with great interest activity towards this end, notably at Scripps Institution of Oceanography (Isaacs, et al., 1963) and Woods Hole Oceanographic Institution (Richardson, et al., 1963). The major difficulty encountered has been to design a suitable mooring system, one which would keep the platform anchored, carry instruments and conductors, and also allow observations at specified depths. A satisfactory mooring system would have been developed long ago if only sea surface observations were required.

The Woods Hole effort has been directed primarily towards getting direct and accurate measurements of the deep currents below the thermocline and has a slack mooring line, whereas that at Scripps has been towards sensing properties down through the mixed layer and thermocline using a taut mooring line. The Woods Hole unit stores the data in subsurface instrumented capsules and requires hauling to retrieve the data, whereas observations from sensors on the Scripps unit are telemetered to and stored in the surface platform.

For the kinds of units fishery investigators require to obtain synoptic data from the upper ocean, the latest Scripps prototype buoy seems to hold promise. Several of these buoys are presently being operated as an experimental network off southern California to obtain a measure of the reliability of the mooring system and the instrument package. The work is being supported by the Office of Naval Research, the Bureau of Commercial Fisheries, and the University of California, Marine Life Research Program. Data being recorded are standard meteorological observations and water temperature at six depths to 150 meters. Current direction and velocity may also be recorded. What will be particularly attractive about the Scripps unit, if it proves to be reliable, will be its cost and its relative ease of handling from research vessels. No good cost estimate is yet available but, hopefully, it will be in the order of \$15,000 to \$20,000, including sensors and telemetering.

When one considers the number of unmanned stations that will be required, it seems that not enough attention has been given to developing the small and less expensive units. The latest Scripps prototype appears to be as well, if not further, advanced than larger and more expensive buoys. If a reliable, small and inexpensive unit is developed to meet the requirements of fishery oceanographers, it should certainly satisfy the needs of the other major users.

There are two other design features besides size and cost of fixed oceanographic stations to which I wish to draw attention. Until I had looked at the advance copy of the program and the titles of the papers, I had not realized how much consideration is being given to developing a stable platform and, by comparison, what little thought seems to be devoted to the mooring system. If this is true, it is disturbing, because stable hulls are only a part of the problem. A suitable mooring system is mandatory for a successful buoy installation. Furthermore, too few people actually involved in the development work have realized that the primary mission requiring the greatest number of unmanned buoys will be to obtain synoptic observations from the uppermost few hundred meters of water. At least I have heard people at Scripps Institution of Oceanography, notably Professor John Isaacs, say that recording subsurface information at the surface is the whole problem and that all others are essentially solved.

As far as the design of the mooring system for subsurface observations is concerned, it seems to me that we should keep reminding ourselves that it is the region above and through the thermocline from which synoptic data are required and for which unmanned buoy networks will be operated. It is in this thin upper layer that changes take place constantly which are ever affecting the weather, the fisheries and defense strategy. The deep ocean is in a kind of "steady state" by comparison, and it is unlikely that oceanographers will require many unmanned buoys for studies of the deep ocean.

The experience at Woods Hole in developing unmanned buoys for deep current measurements suggests that, where synopticity is not required, the design problem is far easier. We are well advised not to consider unmanned buoys for the dual purpose of obtaining observations from the upper layer of the ocean and from the depths.

As to the number of unmanned stations required for the various users, some idea can be obtained from the report of the EPOC committee with respect to synoptic observations from the eastern Pacific. The committee prepared a chart showing two suggested networks in the Pacific, north of 20° S. latitude and east of 180° longitude. One network of 139 stations would be needed for a period of three to five years to further understanding of the major properties and features of the ocean and their variations. Another network of 83 stations would then replace the first for continuous monitoring and forecasting.

Another matter worthy of mention, although perhaps not properly a part of unmanned buoy design, is the development of sensors to take the measurements of properties, which I indicated earlier do not exist. This is an important requirement if unmanned buoys, once developed, are to be operated with maximum benefit and utility. The subject is not prominently mentioned on the program for this meeting but perhaps it is found in some of the papers, or will enter the discussion. The matter of sensor development is felt keenly by fishery oceanographers because there are few suitable sensors for our research.

Fishery Application--Of major concern to fishery oceanographers and the fishing industry alike are year-to-year and season-to-season fluctuations that occur in the catches of many kinds of fishes (and other living resources). These fluctuations complicate the task of determining the optimum harvest and they frequently cause production costs to be higher than if the supply were uniform. Three principal elements operate to cause such fluctuations: the abundance of the organism, its availability (distribution and behavior) to the fishermen, and the amount of fishing effort on the resource. We have learned how to measure changes in fishing effort and to remove its effect on the catch, although not easily, it is true. It is the effect of variations in the environment, changes in the ocean climate if you like, on abundance and availability which now needs major attention if fluctuations in catch are to be understood and predicted. These variations are responsible for much of the time wasted by fishermen in searching for fish; they can even cause the complete failure of a fishery. If such things could be forecast accurately, great economic benefit to the fishing industry would result. California tuna fishermen, for example, often spend more than half of an extended fishing trip running and scouting for tuna. They would profit enormously if accurate forecasts could tell them where and when tuna will be most abundant, because the reduction of time required to catch full loads of fish is the key to lessening production costs and increasing total catch.

Fishery oceanographers are far from understanding the interplay of atmospheric, oceanic and biological processes and their contributions to fluctuations in the availability and abundance of fishes. Forecasting such fluctuations is heavily dependent on adequate understanding of these processes. Our problem is even more difficult than that of the meteorologist or defense oceanographer because some of the effect on fish populations of physical and chemical changes in the environment must be transmitted through several trophic levels in the biota. The current practice is to concentrate on describing the oceanic circulation; to associate physical, chemical and biological parameters of the ocean with the occurrence of fishes; and to document and interpret changes in distribution of the fishes in relation to the properties measured and features described. The bulk of such research activity has been in the Pacific, especially on the tunas.

During the course of the descriptive work, a few attempts have resulted in successful predicting of where and when oceanic patterns associated with tuna availability will occur. Admittedly, even though ability to predict has been obtained, only partial understanding has been achieved. Nevertheless, it has had practical application for the fishing industry, and the empirical relationships derived have become the basis of hypotheses to be investigated and tested rigorously.

The important thing to report to this meeting, however, is that the limited prediction capabilities at hand result from the examination of semi-continuous observations of certain properties. The time-series data presently available are confined to sea surface temperatures and weather reports from merchant and naval shipping and weather ship stations, and certain property measurements obtained from shore and island stations. The latter are not necessarily located where we would like them, and there are critical holiday areas between shipping lanes from which we obtain no information. Also, shipping is sparse in some regions and reports of surface observations are not continuous over an extended period.

The fact that considerable progress is being made with a limited amount of time-series data for a few surface parameters assures us that short-term predictive capabilities for our fisheries would advance rapidly if we had suitably instrumented unmanned buoy networks at our disposal. Many of my colleagues have also expressed the opinion, time and again, that suitable monitoring systems might well provide empirical understanding of some major problems concerning secular changes in the environment which give rise to major "cyclic" changes in the productivity of our fisheries.

CONCLUDING POINTS

What fishery oceanographers and others suggest in the way of future ocean research amounts to a vast undertaking and the effort required will be much greater than that which is now expended. Unmanned buoy networks are only a part of the picture. If you are a fishery oceanographer in the United States, you are sometimes concerned that the effort your group suggests may be out of line with the importance of the existing commercial fisheries. After all, in the United States, there is no immediate shortage in prospect either for animal protein for food or for organic material for industrial uses. On the contrary, we are plagued with agricultural surpluses. In contrast, though, fishery products have kept pace with demand only because of an ever increasing dependence on foreign imports.

Even in the United States, fishery oceanographers quickly lose their inhibitions concerning the need to step up their research efforts when they think of the future of fisheries and when they remind themselves that the information they require about the ocean is the same as that required by other oceanographers. Colleagues in other fields of oceanography, except defense (for which perhaps no cost is excessive), must resolve their apprehension similarly.

It is important to realize that, within 20 to 30 years, the United States will require several billion pounds more of fishery products annually but will not be able to import as much as today. The needs of countries presently exporting fishery products, particularly the land-poor ones, will be staggeringly

higher. The need for protein food is growing by leaps and bounds and the available land will not supply this need. The world will turn more and more to the ocean. It behooves the United States to maintain a strong fishing industry and its high seas fishing rights because we will need more food and organic material from the ocean sooner than we realize.

The increasing complexity of our civilization and the urgent food requirement of the world's rapidly increasing population demand increased knowledge of the ocean and its resources. The compelling need for information will be dominated by the requirement for protein food but other needs will be increasingly served. Many of them we can now identify. Others await us as understanding unfolds.

It would be difficult to suggest a better means to augment the present ocean research effort than by the implementation of networks of unmanned buoys. All groups of oceanographers urgently require such networks. All could share in their operation and all could share in the benefits of the separate analyses that would result.

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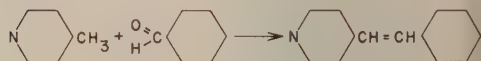
Anesthetic Effect of 4-Styrylpyridine on Lamprey and Fish

JOHN H. HOWELL AND PAUL M. THOMAS

Anesthetic Effect of 4-Styrylpyridine on Lamprey and Fish

The anesthetic property of 4-styrylpyridine (4-SP) on fish and lamprey was first noticed during chemical screening in search of a selective toxicant for larval lamprey (Applegate, Howell, Hall, and Smith, 1957). To assess the possible value of the compound as an anesthetic, we later conducted the experiments reviewed in this report.¹

The compound 4-SP, a fine white powder, is prepared by the following chemical reaction:



Animals exposed to 4-SP to determine its anesthetic qualities were:

Ichthyomyzon unicuspis, silver lamprey
(adults)

Ichthyomyzon spp. (larvae)

¹ Samples of 4-styrylpyridine were purchased from Eastman Organic Chemicals, Distillation Products Industry, Rochester 3, New York.

Lampetra lamottei, American brook lamprey (adults and larvae)

Petromyzon marinus, sea lamprey (adults and larvae)

Catostomus commersoni, white sucker

Lepomis gibbosus, pumpkinseed

Perca flavescens, yellow perch

Pimephales promelas, fathead minnow

Salmo gairdneri, rainbow trout

Lamprey and fish were exposed to 4-SP in 1-liter glass battery jars containing 6 liters of test solution. Solutions were prepared by adding 4-SP, dissolved in acetone, to Lake Huron water to produce the desired concentration. The jars were maintained at 55° F. in a constant-temperature bath and aerated by compressed air delivered through stone air-breakers.

Five animals were exposed at each concentration in tests on adult lamprey and fish. Ten larval lamprey were tested at each level of concentration. The number of animals placed in each batch of test solution depended on their relative size. No more than 1 adult lamprey, 3 fish, or 10 larvae were anesthetized in a single jar because of the possibility of weakening of the solution from absorption by the animals.

Concentrations of 4-SP were selected on the basis of expected susceptibility. Adult lamprey, which were entering the terminal phase of their life cycle, were not exposed to as high concentrations as were larval lamprey and fishes. The maximum concentration to which any animal was exposed was limited to 50 p.p.m. by the low solubility of 4-SP in water.

Anesthetization was assumed to be complete when the animals did not respond to stimulation. They were then transferred to recovery jars which contained 6 liters of aerated Lake Huron water at 55° F. The number of specimens in each recovery jar was the same as in the anesthetic. Recovery of an animal was assumed to have taken place when tactile stimulation produced muscular movement.

Results for each of the species are given in Table 1. Increased dosage usually shortened the time required to produce anesthesia. The time to anesthesia at 20 p.p.m. was nearly the same for the 5 species of fish and 2 of the 3 species of adult lamprey, silver and American brook. Adult sea lamprey and the three

TABLE 1.—Anesthesia and recovery time of lamprey and fish in various concentrations of 4-styrylpyridine (4-SP)

Species and length range (mm)	Dosage (p.p.m.)	Anesthesia and recovery time (hours and minutes; range in parentheses)	
		Muscular movement ceased	Muscular movement resumed
Silver lamprey			
Adult			
222-273	5	8:33 (3:31-10:37)	1:55 (0:33-2:45)
233-270	7.5	3:57 (2:09-6:10)	0:19 (0:04-0:31)
235-255	10	2:01 (1:25-2:55)	0:34 (0:18-0:58)
258-270	15	1:30 (0:48-2:35)	0:18 (0:08-0:44)
255-295	20	0:18 (0:08-0:31)	0:04 (0:01-0:08)
American brook lamprey			
Adult			
134-170	5	2:41 (1:08-3:46)	0:38 (0:05-1:29)
120-152	7.5	1:49 (1:08-2:59)	0:42 (0:19-1:41) ¹
132-158	10	1:16 (0:47-1:34)	1:23 (0:06-3:56)
121-153	15	0:41 (0:21-0:57)	1:06 (0:52-1:24) ¹
127-144	20	0:33 (0:16-0:46)	1:26 (0:12-2:31)
Sea lamprey			
Adult			
325-475	5	3:17 (2:39-3:54) ²	0:07 (0:06-0:08)
320-383	7.5	1:55 (1:13-2:50)	0:02 (0:15-0:26)
333-390	10	1:30 (1:05-2:11)	0:26 (0:19-0:33)
338-440	15	0:51 (0:44-1:14)	0:36 (0:08-1:02)
393-475	20	1:41 (0:54-2:31)	0:17 (0:06-0:32)
Ichthyomyzon sp.			
Larvae			
110-154	20	3:56 (1:30-6:36)	19:54 (13:39-28:45) ³
110-154	30	2:49 (0:57-6:37)	20:59 (14:10-37:30)
110-154	40	3:08 (1:11-5:02)	12:59 (4:14-19:59)
110-154	50	2:28 (1:10-4:25)	10:49 (2:13-17:19)
American brook lamprey			
Larvae			
71-89	20	1:51 (0:54-3:47)	10:10 (9:42-12:35) ⁴
71-89	30	1:42 (0:34-3:03)	11:52 (10:28-14:37) ⁴
71-89	40	1:35 (0:51-2:48)	11:12 (11:00-12:57) ³
71-89	50	1:14 (0:49-2:04)	10:40 (1:37-11:46) ⁴
Sea lamprey			
Larvae			
105-127	20	2:02 (1:25-2:56)	12:11 (6:54-13:19)
105-127	30	1:17 (0:59-1:49)	11:05 (2:50-16:00)
105-127	40	1:05 (0:35-1:57)	12:40 (3:00-16:24)
105-127	50	0:55 (0:18-2:28)	12:11 (3:45-16:34)
White sucker			
117-124	20	0:22 (0:17-0:27)	0:19 (0:11-0:24)
121-154	30	0:14 (0:10-0:24)	0:10 (0:08-0:12)
117-139	40	0:17 (0:12-0:22)	0:15 (0:11-0:20)
99-130	50	0:16 (0:09-0:20)	0:14 (0:06-0:27)
Pumpkinseed			
102-133	20	0:30 (0:15-1:00)	0:15 (0:07-0:24)
95-144	30	0:35 (0:30-0:41)	0:21 (0:15-0:29)
109-144	40	0:15 (0:10-0:27)	0:18 (0:09-0:41)
112-136	50	0:21 (0:08-0:55)	0:28 (0:16-0:36)
Yellow perch			
101-124	20	0:13 (0:11-0:15)	0:13 (0:08-0:20)
103-115	30	0:11 (0:10-0:14)	0:18 (0:07-0:34)
106-117	40	0:10 (0:08-0:14)	0:11 (0:07-0:16)
97-120	50	0:08 (0:08-0:09)	0:09 (0:06-0:12)
Fathead minnow			
44-59	20	0:36 (0:30-0:48)	0:38 (0:21-0:53)
47-52	30	0:18 (0:15-0:22)	0:10 (0:04-0:21) ⁵
48-56	40	0:22 (0:15-0:30)	0:24 (0:03-0:38)
44-53	50	0:18 (0:12-0:26)	0:25 (0:07-0:51) ⁵
Rainbow trout			
170-180	20	0:25 (0:18-0:28)	0:08 (0:05-0:12)
160-190	30	0:22 (0:17-0:25)	0:07 (0:05-0:09)
160-180	40	0:20 (0:16-0:24)	0:07 (0:04-0:13)
160-190	50	0:12 (0:08-0:23)	0:06 (0:04-0:07)

¹ One of 5 animals did not recover.

² Muscular movement ceased in only 2 of 5 animals. The 3 that had continued muscular movement were exposed for 22 hours, 24 minutes.

³ Two of 10 animals did not recover.

⁴ One of 10 animals did not recover.

⁵ One of 5 animals did not recover.

groups of larval lamprey were more resistant. Larval lamprey, as a group, were the most resistant to the anesthetic effects of 4-SP.

The relation of concentration to recovery time differed among the test animals. Recovery times decreased as concentrations of 4-SP increased in silver lamprey adults and larval *Ichthyomyzon* spp. Recovery times increased with increased concentration in American brook lamprey adults, and to some extent sea lamprey adults. Recovery times were similar at all concentrations in the remaining species.

Two hundred ninety-five lampreys and fishes were exposed to 4-SP during these experiments; only 4.4 percent died. This mortality is low considering the degree of anesthetization produced. The loss of reflex reactivity in fish is associated with respiratory and cardiac collapse (McFarland, 1959). This degree of anesthetization is greater than is normally required for the handling of aquatic animals. It does, however, provide a convenient criterion for evaluating the effect of an anesthetic on a variety of species.

Tricane methanesulfonate (M.S. 222) has been used to anesthetize adult sea lamprey at concentrations of 50–2,000 p.p.m. (Thorson, 1959). The literature contains no data on the effect of anesthetics on larval lampreys. Considerable research has been conducted on the effects of various anesthetics and levels of anesthetization of fishes. McFarland (1960) gave data on 10 materials that have been used for anesthetization or sedation of fresh- and salt-water fish. For total loss of reflex reactivity within 4 hours, he recommended concentrations of these materials ranging from 6.6 p.p.m. for M.S. 222 to 3,434 p.p.m. for urethane.

Recent works by Meister and Ritzi (1959) on eastern brook trout, Parkhurst and Smith (1957) on spawning rainbow trout, and Webb (1958) on bluegill and other warmwater fishes unanimously recommended M.S. 222. Suggested concentrations ranged from 106 p.p.m. to 1,000 p.p.m., depending on the species, water temperature, and degree of anesthetization desired.

The concentrations used by these researchers

and in our experiments make it difficult to evaluate the utility of 4-SP in comparison with other fish anesthetics. The times to anesthetization and for recovery with 4-SP are however, similar to those determined at considerably higher concentrations of other anesthetics.

The anesthetic, 4-SP, can be handled safely by humans according to mammalian toxicity tests. The acute oral LD-50 to male albino rats of the Sprague-Dawley strain was 2 grams per kilogram and acute dermal LD-50 for the same animal was in excess of 9.4 grams per kilogram. A primary skin-irritation test on white rabbits indicated the material was nonirritating.² The compound may be purchased at a price competitive with that of M.S. 222.

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² Data obtained from assay report of the Wisconsin Alumni Research Foundation Laboratories, Madison Wisconsin.

**Synergism of
5, 2'-Dichloro-4'-Nitro Salicylanilide
and 3-Trifluormethyl-4-Nitrophenol
in a Selective Lamprey Larvicide**



Great Lakes Fishery Commission

The Great Lakes Fishery Commission was established by the Convention on Great Lakes Fisheries, between Canada and the United States, ratified on October 11, 1955. It was organized in April, 1956 and assumed its duties as set forth in the Convention on July 1, 1956. The Commission has two major responsibilities: the first, to develop co-ordinated programs of research in the Great Lakes and, on the basis of the findings, recommend measures which will permit the maximum sustained productivity of stocks of fish of common concern; the second, to formulate and implement a program to eradicate or minimize sea lamprey populations in the Great Lakes. The Commission is also required to publish or authorize the publication of scientific or other information obtained in the performance of its duties.

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SYNERGISM OF 5, 2'-DICHLORO-4'-NITRO-SALICYLANILIDE
AND 3-TRIFLUORMETHYL-4-NITROPHENOL
IN A SELECTIVE LAMPREY LARVICIDE

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SYNERGISM OF 5, 2'-DICHLORO-4'-NITRO-SALICYLANILIDE AND 3-TRIFLUORMETHYL-4-NITROPHENOL IN A SELECTIVE LAMPREY LARVICIDE

ABSTRACT

The molluscicide 5,2'-dichloro-4'-nitro-salicylanilide improves the action of the selective lamprey larvicide 3-trifluormethyl-4-nitrophenol (TFM). Laboratory bioassays with mixtures containing various percentages of the two chemicals indicated that up to 3 percent of the salicylanilide could be added to TFM without destroying its selective toxicity, but other considerations made use of a 2-percent mixture most advisable. Tests of mixtures containing 2 percent of the salicylanilide in waters from 26 different sources brought out the effect of chemical condition of the water on the toxicity, selectivity, and relative degree of improvement over TFM alone. Simulated stream treatments, in concrete raceways, and six treatments of streams tributary to Lake Michigan substantiated the laboratory findings. Field use of the mixture reduces treatment costs by approximately 50 percent.

Introduction

The discovery that chemicals belonging to the class of mononitrophenols containing halogens were selectively toxic for larvae of sea lamprey, *Petromyzon marinus*, was a significant advance in the attempt to control this species in the upper Great Lakes (Applegate, Howell, and Smith, 1958). One of these nitrophenols, 3-trifluormethyl-4-nitrophenol (TFM), was studied extensively and subsequently developed for field use (Applegate, *et al.*, 1961).

The first applications of TFM were made in streams tributary to Lake Superior in 1958. It has since been widely used in the Lake Superior and Lake Michigan basins in the treatment of streams containing sea lamprey larvae. Results of these treatments indicate that selective toxicants can reduce the number of sea lamprey.¹ The large amount of TFM required and its high cost have prompted a search for materials which might supplement or replace it in the control program.

¹ Report of Annual Meeting, Great Lakes Fishery Commission, June 26 and 27, 1963, Ann Arbor, Michigan.

In the screening of various chemicals, it was discovered that 5,2'-dichloro-4'-nitro-salicylanilide was extremely toxic to sea lamprey larvae. Tests revealed that small amounts of 5, 2'-dichloro-4'-nitro-salicylanilide improved the toxicity of TFM without affecting significantly its selectivity toward lamprey larvae. Synergism, as used in this report, is considered to be the simultaneous action of separate agencies which, together, have greater total effect than the sum of their individual effects. This synergy and its effect on the toxicity and selectivity to lamprey larvae and certain fishes are the subject of this report.

5,2'-dichloro-4'-nitro-salicylanilide is commercially available, under the trade name Bayluscide,² as a 70-percent wettable powder of its ethanolamine salt. It is used principally as a molluscicide for the control of freshwater snails. A considerable amount of literature is available on Bayluscide dealing with its physical and chemical properties, influence of environmental factors on its efficiency, acute and chronic mammalian toxicity, mode of toxic action, and results of field trials as a molluscicide. Some of the more important and comprehensive studies have been published as a single volume.³

Bioassays

Laboratory tests were conducted with Bayluscide and a commercially available, 30-percent (by weight) aqueous formulation of the sodium salt of TFM. Various percentage mixtures of the two compounds were prepared by suspending an appropriate amount of Bayluscide in the TFM formulation. The low solubility of Bayluscide in distilled water, 230 ppm $\pm$ 50 ppm at room temperature, required that these suspensions be agitated until their final dilution to test concentrations.

Laboratory facilities, equipment, and procedures were similar to those described by Applegate, *et al.*, (1957, 1961). Larval sea lampreys and fingerling rainbow trout, *Salmo gairdneri*, from 3.5 to 5.0 inches in total length, served as test animals. Lampreys were collected from streams tributary to Lakes Michigan and Huron. Rainbow trout were hatchery-reared fish provided by the Michigan Department of Conservation.

Tests were set up by first pouring 5 liters of water in 10-liter (10-inch diameter) glass battery jars placed in a 55°

² Registered trade mark of Farbenfabriken Bayer AG, Leverkusen, Germany.

³ *Pflanzenschutz Nachrichten "Bayer"*, Vol. XV No. 1, 1962; published by Farbenfabriken Bayer AG, Leverkusen, Germany.

F. constant-temperature bath. Two lamprey larvae and 2 rainbow trout were added to each jar. Oxygen levels were maintained by stone aerators at near-saturation during the test. The containers were covered with a sheet of clear glass to prevent the escape of fish. Test animals were left undisturbed for 1 to 2 hours to permit them to adapt to the test environment.

Bioassay concentrations and the final 6-liter test volume were obtained by adding 1 liter of an aqueous stock of appropriate strength to each test jar. The aqueous stocks were prepared from samples of the chemicals weighed to the nearest milligram on a Volland Speedigram balance. The final concentrations in the test containers were checked colorimetrically. The absorption maxima for Bayluscide and TFM, 385 m μ and 395 m μ respectively, are sufficiently close to allow mixtures to be analyzed by modifying slightly the method described for TFM by Smith, Applegate, and Johnson (1960).

Dilution waters for test solutions were obtained from several sources depending on the purpose of the experiments. Tests to compare the biological activity of TFM, Bayluscide, and mixtures containing various percentages of the two compounds were made in a single lot of water taken from Hammond Bay, Lake Huron. This water was stored in a covered concrete tank. Daily measurements of the physical and chemical characteristics of this water did not change significantly during storage. Average values over the period were: oxygen, 11.4 ppm; carbon dioxide, 1.0 ppm; methyl-orange alkalinity, 88.0 ppm; phenolphthalein alkalinity, 3.5 ppm; pH, 8.2; conductivity, 180.9 μ mhos/18°C.

Applegate, *et al.*, (1961) noticed that the biological activity of TFM varied with physical and chemical changes in the dilution water. Instances have also been reported where TFM retained its toxicity but lost its selectivity toward larval lampreys (Howell and Marquette, 1962). The extent to which these variations might exist with a mixture of TFM and Bayluscide was determined by assays in waters collected from widely separated sources in the Lake Huron and Lake Michigan basins. Physical and chemical analyses of these dilution waters were made immediately before their use.

Twenty replications, based on a total of 40 specimens of each species, were made at each concentration in the tests to determine the relative toxicity of TFM, Bayluscide, and various percentage mixtures of the two. The responses of the test animals were observed hourly during the 20-hour test period. In assays conducted to test the effect of varying chemical and physical characteristics of the dilution water, 4 replications

were made at each concentration. This reduction in the number of tests was necessitated by the limited volume of water that could be transported to the laboratory. Observations of each test in this series were made hourly for the first 8 hours and at the end of 20 hours.

The combined data from the replications at each concentration were tabulated at the completion of the bioassay. Assays were designed to produce data from which two levels of concentration—minimum lethal and maximum allowable—could be determined. The minimum lethal value (MLC_{100}) is the lowest concentration in a series that produces 100-percent mortality among larval lampreys. The maximum allowable concentration (MAC_{25}) is the highest which did not kill more than 25 percent of the rainbow trout. Howell and Marquette (1962) used these two values in applying bioassay data to the treatment of streams. They termed the difference between MLC_{100} and MAC_{25} as the working range; the ratio of the working range to MLC_{100} is the permissible additional flow. This ratio indicates the factor by which volume of flow at the point of application may increase in a stream treated at the MAC_{25} level before the concentration will be diluted to the MLC_{100} . They considered a permissible additional flow of 1.0 (*i.e.*, a doubling) as the lowest acceptable for stream treatment.

Because of the high toxicity of Bayluscide to larval lampreys, the effect of adding small amounts of the compound to TFM were investigated. Bioassays were conducted with TFM, Bayluscide, and mixtures of the two in which Bayluscide made up 1, 2, 3, 4, and 5 percent of the total weight.

Evaluation of the relative merit of TFM, Bayluscide, and mixtures of the two must take into consideration the toxicity to both test species and the margin of selectivity as reflected in the permissible additional flow. Bayluscide is more than 43 times as toxic to larval lampreys as TFM, but its toxicity to rainbow trout is so great that it is practically non-selective between the two. The addition of Bayluscide to TFM progressively reduced MLC_{100} , MAC_{25} , and working range as the percentage of Bayluscide increased from 1 to 5 percent (Table 1). Exceptions were the mixtures containing 3- and 4-percent Bayluscide where the values of MLC_{100} were the same. The permissible additional flow was higher at 1-percent Bayluscide (1.66) than with TFM alone (1.29), but decreased to 1.00 when Bayluscide made up 2 or 3 percent and less than 1.00 when Bayluscide exceeded 3 percent.

Additions of more than 3 percent of Bayluscide to TFM can not be justified because they result in a permissible

Table 1.—Toxicity of TFM, Bayluscide, and various mixtures of the two compounds to sea lamprey larvae and rainbow trout

[Tests conducted for a 20-hour period at a water temperature of 55° F.; test water was a single lot taken from Hammond Bay, Lake Huron.]

Percentage composition of test material		Minimum lethal concentration for larval lamprey (ppm)	Maximum allowable concentration for rainbow trout (ppm)	Working range (ppm)	Permissible additional flow ¹ (cfs)
TFM	Bayluscide				
100	0	3.50	8.00	4.50	1.29
99	1	2.25	6.00	3.75	1.66
98	2	2.00	4.00	2.00	1.00
97	3	1.50	3.00	1.50	1.00
96	4	1.50	2.50	1.00	0.66
95	5	1.13	2.00	0.87	0.77
0	100	0.08	0.09	0.01	0.13

¹ Per 1 cfs of flow at point of treatment at the maximum allowable concentration.

additional flow less than the limiting value of 1.00, but lesser percentages produce significant increases in toxicity to larvae without reducing selectivity below a practical level. The MLC_{100} for mixtures containing 1-, 2-, and 3-percent Bayluscide (2.25, 2.00, and 1.50 ppm) represent reductions of 36, 43, and 57 percent from the value of 3.50 ppm for TFM. Corresponding decreases in MAC_{25} were 25, 50, and 62 percent.

The greatest saving in the amount of toxicant required to kill larval lampreys without reducing selectivity below a practical limit was with the mixture containing 3-percent Bayluscide. Other considerations led us, however, to accept the lesser benefit of the 2-percent mixture for further work.

Preliminary testing with mixtures of TFM and Bayluscide to determine the need for a study such as reported here indicated that in some test waters the 3-percent mixture exceeded the level at which selectivity starts to decline below the acceptable limit. Since the material was to be used in waters with a wide range of chemical and physical characteristics, it seemed desirable to concentrate further study on the 2-percent mixture which had consistently produced acceptable selectivity.

A second consideration favoring the use of the 2-percent mixture was the physical characteristics of the TFM-Bayluscide combination. Bayluscide is largely in suspension in the aqueous mixture of toxicants. Even though the mixture is agitated mechanically throughout a chemical application the Bayluscide tends to settle out. This tendency results in slight fluctuations in the percentage composition of the toxicants; it seemed discreet, therefore, to use the safer 2-percent mixture.

Proof of the synergistic action of Bayluscide appears in the records of the actual amount of TFM and Bayluscide in each of the percentage mixtures at the MLC_{100} and MAC_{25} levels (Table 2). The amount of each compound present in the MLC_{100} levels for the mixtures is considerably below the concentration required to produce the same mortality with the compounds separately. The same synergy is evident in the response of rainbow trout to mixtures containing 1- and 2-percent Bayluscide. Mixtures containing 3, 4, and 5 percent are not synergistic since the amount of Bayluscide is equal to or greater than that required to produce a MAC_{25} .

The evidence of synergistic action of the mixture containing 2-percent Bayluscide and 98-percent TFM is especially significant since this mixture was selected for additional testing and field use. The MLC_{100} for the 2-percent mixture is 2.00 ppm—0.04 ppm Bayluscide and 1.96 ppm TFM. These concentrations individually are non-toxic to lamprey larvae, but they coact to produce 100-percent mortality. Similarly,

Table 2.—Actual amount of TFM and Bayluscide in the minimum lethal and maximum allowable concentrations of various percentage mixtures
[Based on same bioassays as Table 1.]

Percentage composition of test material	TFM Bayluscide	Minimum lethal concentration for larval lamprey (ppm)	Amount in minimum lethal concentration (ppm)		Maximum allowable concentration for rainbow trout (ppm)	Amount in maximum allowable concentration (ppm)	
			TFM	Bayluscide		TFM	Bayluscide
100	0	3.50	3.50	...	8.00	8.00	...
99	1	2.25	2.23	0.02	6.00	5.94	0.06
98	2	2.00	1.96	0.04	4.00	3.92	0.08
97	3	1.50	1.46	0.05	3.00	2.91	0.09
96	4	1.50	1.44	0.06	2.50	2.40	0.10
95	5	1.13	1.07	0.06	2.00	1.90	0.10
0	100	0.08	...	0.08	0.09	...	0.09

the MAC_{25} value for the same mixture is 4.00 ppm, of which 0.08 ppm is Bayluscide and 3.92 ppm is TFM. Neither of these concentrations is toxic to rainbow trout; nevertheless, they coact to produce 25-percent trout mortality.

Chemical and physical characteristics of natural waters strongly influence the toxicity of TFM (Applegate, *et al.*, 1961). Kanayama (1963) described a method for estimating the MLC_{100} and MAC_{25} for TFM from the alkalinity and conductivity of the test waters. To determine the effect of these factors on the relative toxicity of TFM and TFM plus 2-percent Bayluscide (TFM-2B) comparative bioassays were run in dilution waters from 26 different sources. These waters varied widely enough in pH, conductivity, and alkalinity to be representative of most streams infested with sea lamprey larvae. No detailed analysis was made of these bioassays to determine if the relation of alkalinity and conductivity to biological activity which Kanayama (1963) noted for TFM also applies to TFM-2B. The results indicate, however, that a similar correlation exists.

The data on physical and chemical properties of the 26 dilution waters and the results of the 26 assays (Table 3) bring out the influence of the quality of the dilution water. Both TFM and TFM-2B were more effective in the softer waters with the lower pH values. As conductivity, alkalinity, and pH increased, the MLC_{100} value became greater. A comparison of the MLC_{100} values of TFM to the same values for TFM-2B indicates that their relative toxicity is also influenced by water quality. In the softest water tested, Milligan Creek, Presque Isle County, Michigan, the two materials were equally toxic to larval lampreys. As water hardness increased, the differential toxicity increased to approximately a 2:1 ratio of TFM to TFM-2B.

The values of MLC_{100} , MAC_{25} , and working range in all 26 dilution waters (Table 4) were lower for TFM-2B than for TFM. Differences in the permissible additional flow varied randomly. The values were the same for TFM and TFM-2B in 7 streams. TFM had the higher value in 11 streams and TFM-2B in 8. No complete loss of selectivity of the kind noted by Howell and Marquette (1962) appeared. The lowest permissible additional flows for both TFM and TFM-2B (1.00 and 1.33 cfs) were for water from Good Harbor Creek, Leelanau County, Michigan. The highest values were 5.00 with TFM in water from Lake Huron, Presque Isle County, Michigan, and 4.67 with TFM-2B in water from Devils River, Alpena County, Michigan.

Table 3.—Variations in the biological activity of TFM and TFM-2B in waters of differing physical and chemical characteristics
 [Tests conducted for a 20-hour period at a water temperature of 55° F.; all streams in State of Michigan.]

Source of test water	Minimum lethal concentration (ppm)		Maximum allowable concentration (ppm)		Properties of test water		
	TFM	TFM-2B	TFM	TFM-2B	Conductivity (μ mhos/18° C.)	CO ₂ (ppm)	Alkalinity (ppm CaCO ₃) pH
Milligan Creek							
Presque Isle County	1.0	1.0	5.0	4.0	99.3	3.4	67.5 7.3
Lake Huron							
Presque Isle County	1.5	1.25	9.0	4.5	181.6	1.3	104.0 7.9
Devils River							
Alpena County	3.0	1.5	13.0	8.5	265.4	2.1	171.0 7.9
Little Fishdam River							
Delta County	4.0	2.0	18.0	9.0	214.4	3.0	120.5 7.6
Cheboygan River							
Cheboygan County	4.0	2.0	18.0	9.0	250.6	1.4	184.0 8.1
Trout River							
Presque Isle County	4.0	2.0	17.0	8.5	268.6	3.3	210.0 7.8
Carp Creek							
Presque Isle County	4.0	2.5	22.0	9.0	202.0	1.0	181.5 8.4
Crystal River							
Leelanau County	5.0	3.0	14.0	10.0	227.9	1.0	130.0 8.4

(continued)

Table 3.—Continued

Source of test water	Minimum lethal concentration (ppm)		Maximum allowable concentration (ppm)		Properties of test water			
	TFM	TFM-2B	TFM	TFM-2B	Conductivity (μ mhos/180 C.)	CO ₂ (ppm)	Alkalinity (ppm CaCO ₃)	pH
Acme Creek								
Grand Traverse County	5.0	3.0	22.0	11.0	247.5	2.9	154.0	7.7
Good Harbor Creek								
Leelanau County	5.0	3.0	10.0	7.0	250.7	1.0	132.0	8.4
Betsie River								
Benzie County	5.0	3.0	14.0	10.0	260.9	1.0	148.5	8.2
Davenport Creek								
Mackinac County	5.0	3.5	18.0	11.0	214.8	1.0	172.0	8.3
Carp Lake River								
Emmet County	5.0	3.5	22.0	12.0	268.5	1.0	196.5	8.4
Manistee River								
Manistee County	6.0	3.0	20.0	9.0	260.5	1.0	150.0	8.4
Platte River								
Benzie County	6.0	3.0	20.0	10.0	266.0	1.2	155.0	8.1
Pere Marquette River								
Mason County	6.0	3.0	22.0	11.0	297.3	1.4	145.0	8.0
Jordan River								
Charlevoix County	6.0	3.0	20.0	8.0	303.8	1.4	221.0	8.2

(continued)

Table 3.—Continued

Source of test water	Minimum lethal concentration (ppm)		Maximum allowable concentration (ppm)		Properties of test water			
	TFM	TFM-2B	TFM	TFM-2B	Conductivity (μ mhos/18° C.)	CO ₂ (ppm)	Alkalinity (ppm CaCO ₃)	pH
Au Gres River Arenac County	6.0	3.0	18.0	9.0	544.0	1.5	240.0	8.2
Little Manistee River Manistee County	6.0	3.5	18.0	10.0	223.1	1.0	140.0	8.3
Mitchell Creek Grand Traverse County	6.0	4.0	26.0	13.0	311.6	1.0	250.0	8.5
Pentwater River Mason County	7.0	2.5	24.0	12.0	320.6	1.0	163.0	8.2
Boardman River Grand Traverse County	7.0	3.5	22.0	10.0	250.5	1.0	136.0	8.1
Lincoln River Mason County	7.0	3.5	20.0	11.0	297.6	1.2	156.0	8.1
Crow River Mackinac County	9.0	4.5	22.0	12.0	338.7	1.2	203.0	8.2
Hospital Creek Grand Traverse County	10.0	4.0	30.0	15.0	438.8	2.1	217.0	8.0
Hound Creek Benzie County	10.0	5.0	28.0	14.0	385.9	2.2	230.0	8.0

Table 4.—Comparison of toxicity, working range, and permissible additional flow of TFM and TFM-2B in dilution waters from 26 sources

[Based on same bioassays as Table 3.]

Source of test water	Minimum lethal concentration for larval lamprey (ppm)		Maximum allowable concentration for rainbow trout (ppm)		Working range (ppm)		Permissible additional flow ¹ (cfs)	
	TFM	TFM-2B	TFM	TFM-2B	TFM	TFM-2B	TFM	TFM-2B
Milligan Creek								
Presque Isle County	1.0	1.0	5.0	4.0	4.0	3.0	4.00	3.00
Lake Huron								
Presque Isle County	1.5	1.25	9.0	4.5	7.5	3.25	5.00	2.60
Devils River								
Alpena County	3.0	1.5	13.0	8.5	10.0	7.0	3.33	4.67
Little Fishdam River								
Delta County	4.0	2.0	18.0	9.0	14.0	7.0	3.50	3.50
Cheboygan River								
Cheboygan County	4.0	2.0	18.0	9.0	14.0	7.0	3.50	3.50
Trout River								
Presque Isle County	4.0	2.0	17.0	8.5	13.0	6.5	3.25	3.25
Carp Creek								
Presque Isle County	4.0	2.5	22.0	9.0	18.0	6.5	4.50	2.60
Crystal River								
Leelanau County	5.0	3.0	14.0	10.0	9.0	7.0	1.80	2.33

(continued)

Table 4.—Continued

Source of test water	Minimum lethal concentration for larval lamprey (ppm)		Maximum allowable concentration for rainbow trout (ppm)		Working range (ppm)		Permissible additional flow 1 (cfs)	
	TFM	TFM-2B	TFM	TFM-2B	TFM	TFM-2B	TFM	TFM-2B
Acme Creek								
Grand Traverse County	5.0	3.0	22.0	11.0	17.0	8.0	3.40	2.67
Good Harbor Creek								
Leelanau County	5.0	3.0	10.0	7.0	5.0	4.0	1.00	1.33
Betsie River								
Benzie County	5.0	3.0	14.0	10.0	9.0	7.0	1.80	2.33
Davenport Creek								
Mackinac County	5.0	3.5	18.0	11.0	13.0	7.5	2.60	2.14
Carp Lake								
Emmet County	5.0	3.5	22.0	12.0	17.0	8.5	3.40	2.43
Manistee River								
Manistee County	6.0	3.0	20.0	9.0	14.0	6.0	2.33	2.00
Platte River								
Benzie County	6.0	3.0	20.0	10.0	14.0	7.0	2.33	2.33
Pere Marquette River								
Mason County	6.0	3.0	22.0	11.0	16.0	8.0	2.67	2.67
Jordan River								
Charlevoix County	6.0	3.0	20.0	8.0	14.0	5.0	2.33	1.67

(continued)

Table 4.—Continued

Source of test water	Minimum lethal concentration for larval lamprey (ppm)		Maximum allowable concentration for rainbow trout (ppm)		Working range (ppm)		Permissible additional flow ¹ (cfs)	
	TFM	TFM-2B	TFM	TFM-2B	TFM	TFM-2B	TFM	TFM-2B
Au Gres River								
Arenac County	6.0	3.0	18.0	9.0	12.0	6.0	2.00	2.00
Little Manistee River								
Manistee County	6.0	3.5	18.0	10.0	12.0	6.5	2.00	1.86
Mitchell Creek								
Grand Traverse County	6.0	4.0	26.0	13.0	20.0	9.0	3.33	2.25
Pentwater River								
Mason County	7.0	2.5	24.0	12.0	17.0	7.5	2.43	3.80
Boardman River								
Grand Traverse County	7.0	3.5	22.0	10.0	15.0	6.5	2.14	1.86
Lincoln River								
Mason County	7.0	3.5	20.0	11.0	13.0	7.5	1.86	2.14
Crow River								
Mackinac County	9.0	4.5	22.0	12.0	13.0	7.5	1.44	1.67
Hospital Creek								
Grand Traverse County	10.0	4.0	30.0	15.0	20.0	11.0	2.00	2.75
Hound Creek								
Benzie County	10.0	5.0	28.0	14.0	18.0	9.0	1.80	1.80

¹ Per 1 cfs of flow at point of treatment at the maximum allowable concentration.

Raceway Tests

Methods

Experiments with TFM and TFM-2B in running-water raceways measured their biological activity under conditions approaching a natural stream environment. Facilities and techniques were essentially the same as those used by Applegate, *et al.*, (1961) for a series of "simulated stream" tests with TFM. The raceways are a pair of concrete troughs, each 65 feet long, 6 feet wide, and 30 inches deep. A "head" flume, common to both races, delivers a stabilized flow of Lake Huron water to them from a surge tank. The volume of water entering each raceway was measured through a "V" weir. Water depth was maintained at 18 inches by stopboards in the discharge flumes.

Rainbow trout, brook trout, *Salvelinus fontinalis*, and brown trout, *Salmo trutta*, were used in the raceway tests. The trout, which ranged from 10 to 14 inches in total length, were allowed to move unrestricted within the 65-foot-long test area. Larval lampreys were confined in 4 cylindrical screen cages. The solid-walled lower 6 inches of each cage contained washed beach sand. Larvae were placed in the cages and allowed to burrow before each test was started. Two cages were placed at the mid-point of the race and 2 at the lower end. Confinement of larval lampreys to cages permitted rapid and accurate determinations of mortality. Hourly observations were made on all animals during the 22-hour test period.

Concentrated, aqueous solutions of TFM and TFM-2B were metered into the raceways by fluid-proportioning devices. TFM was fed directly to the incoming water as it passed through the "V" weir by means of a fuel-pump feeder (Anderson, 1962). The TFM-2B concentrate was pumped by a motor-driven, dual-piston proportioning device and delivered, diluted with flush water, to a perforated pipe located at the head of the raceway.

The proportioning devices were checked hourly to assure a constant feed rate. Water flow through the raceways was controlled at 0.336 cfs. The concentration of TFM or TFM-2B was regulated by varying the strength of the stock solution. Concentrations in each test were checked by periodic colorimetric analysis of samples from the head, middle, and tail of each raceway.

Ten pairs of simulated stream tests were made with TFM and TFM-2B. In each pair, the concentrations of the two materials in the two raceways were identical. Concentrations tested

Table 5.—Comparative toxicity of TFM and TFM-2B in raceway tests

[The figures in parentheses indicate the number of specimens of each species exposed; test water from Hammond Bay, Lake Huron.]

Concentration (ppm)	Mean water temperature (° F.)	TFM			TFM-2B		
		Percentage mortality			Percentage mortality		
		Larval lamprey	Rainbow trout	Brook trout	Larval lamprey	Rainbow trout	Brook trout
1.0	64.5	0 (100)	0 (5)	0 (5)	0 (100)	0 (5)	0 (5)
1.5	62.5	0 (100)	0 (5)	0 (5)	97 (96)	0 (5)	0 (5)
2.0	66.0	9 (98)	0 (5)	0 (5)	98 (102)	0 (5)	0 (5)
2.5	62.0	52 (100)	0 (5)	0 (5)	100 (100)	0 (5)	0 (5)
3.0	66.0	85 (93)	0 (5)	0 (5)	100 (100)	0 (5)	0 (5)
4.0	63.0	100 (98)	0 (5)	0 (5)	100 (98)	0 (5)	0 (5)
5.0	64.5	100 (100)	0 (5)	0 (5)	100 (100)	0 (5)	0 (5)
8.0	63.0	...	0 (10)	0 (10)	...	10 (10)	0 (10)
10.0	61.5	...	0 (10)	0 (10)	...	0 (10)	0 (10)
12.0	63.5	...	0 (10)	0 (10)	...	70 (10)	60 (10)

ranged from 1.0 to 12.0 ppm. Larval lampreys were used in tests at each concentration up to 5.0 ppm. Trout were used in all tests.

Chemical and physical characteristics of the test water were checked daily during the 2-week test period. Values were: oxygen, 8.3 to 8.5 ppm; carbon dioxide, less than 1.0 ppm; methyl-orange alkalinity, 83.0 to 97.0 ppm; phenolphthalein alkalinity, trace to 4.5 ppm; pH, 8.0 to 8.3; conductivity, 176.4 to 192.6 μ mhos/18° C.

The results of the raceway tests (Table 5) are similar to those from the laboratory bioassays. The MLC_{100} for TFM was 4.0 ppm, whereas only 2.5 ppm of TFM-2B were required to kill all larvae. No trout died at any of the TFM concentrations from 1.0 to 10.0 ppm, but 2 of 10 brook trout died at 12.0 ppm. TFM-2B was more toxic to trout than was TFM. Two of 5 brown trout died at 4.0 ppm and trout of at least one species died at each higher concentration. Mortality at 12.0 ppm was 60 to 90 percent.

Comparison of the records of time to death of larval lampreys at various concentrations of TFM and TFM-2B (Table 6) again indicate the much greater toxicity of the mixture. At 2.5 ppm, for example, TFM-2B killed all the larvae in 9 hours, whereas 5.0 ppm of TFM were required for 100-percent mortality in the same time interval. Records for other concentrations bring out similar contrasts.

Stream Treatments

The final phase in the development of TFM (Applegate, *et al.*, 1961) was a series of 3 experimental stream treatments. These treatments were necessary to develop and test various field methods. It was not considered necessary to follow the same procedure with TFM-2B since no basic changes were required in application procedures. The early treatments with TFM-2B are best described as "semi-experimental."

Six streams tributary to the eastern shore of Lake Michigan were treated with TFM-2B in the fall of 1963 as part of a continuing program to control sea lampreys in Lake Michigan. Most relevant to the present report is a comparison of the actual chemical cost with TFM-2B and the estimated cost with TFM in each of these treatments (Table 7).⁴ The cost of chemical for treating these 6 streams was reduced by \$27,094. This saving exceeds 50 percent of the estimated cost of \$53,091 for treating the same waters with TFM.

⁴ Interim Report on Sea Lamprey Control, June to November 1963, Bureau of Commercial Fisheries, Ann Arbor, Michigan.

Table 6.—Percentage mortality of sea lamprey larvae at each observation period in raceway tests
 [The data for 1.0 ppm have been omitted since no larvae were killed with either compound.]

Time in hours	Concentration (ppm)									
	1.5		2.0		2.5		3.0		4.0	
	TFM	TFM-2B	TFM	TFM-2B	TFM	TFM-2B	TFM	TFM-2B	TFM	TFM-2B
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	5
3	0	0	0	0	0	0	13	0	34	1
4	0	0	0	0	0	8	51	2	78	35
5	0	0	0	0	0	42	85	12	96	66
6	0	0	0	2	0	80	95	31	100	84
7	0	0	0	12	0	94	6	62	...	92
8	0	2	0	39	3	99	14	74	...	95
9	0	6	0	66	7	100	24	74	...	100
10	0	9	0	77	9	...	35	83	...	...
11	0	23	0	88	11	...	52	92	...	...
12	0	33	0	90	17	...	60	96	...	...
13	0	51	0	94	20	...	68	96	...	...
14	0	61	1	95	26	...	72	98	...	...

(Continued)

Table 6.—Continued

Time in hours	Concentration (ppm)									
	1.5	2.0	2.5	3.0	4.0	5.0	TFM-2B	TFM-2B	TFM-2B	TFM-2B
15	0	76	5	95	29	...	76	...	98	...
16	0	79	6	96	32	...	78	...	100	...
17	0	87	6	96	35	...	78	...	...	...
18	0	92	6	97	38	...	78	...	...	...
19	0	93	6	98	42	...	82	...	...	...
20	0	96	8	...	46	...	82	...	...	...
21	0	96	9	...	49	...	83	...	...	...
22	0	97	9	...	52	...	85	...	...	...

¹ From the 7th to 12th hour only 1 larvae continued to survive. This larvae probably had received a lethal dose of TFM-2B prior to its death at the 12th hour.

Table 7.—Comparison of actual chemical costs with TFM-2B (98 percent by weight 3-trifluormethyl-4-nitrophenol and 2 percent of the synergist, 5,2'-dichloro-4'-nitro-salicylanilide) and estimated cost with TFM

Stream	Discharge at mouth (cfs)	TFM			TFM-2B			Actual Cost
		Concentration (ppm)	Pounds of active ingredient	Estimated cost	Concentration (ppm)	Pounds of active ingredient	Synergist	
		Minimum effective	Maximum allowable		Minimum effective	Maximum allowable		
Mitchell Creek	35	11	20	\$ 1,045	5.0	12.0	162	4.5 \$ 502
Boardman River	236	10	24	23,384	4.5	8.0	3,585	100.0 10,385
Good Harbor Creek ¹	12	8	16	1,223	3.5	7.0	180	5.0 558
Crystal River ¹	16	6	14	1,276	3.5	6.0	216	6.0 669
Upper Platte River	129	6	16	11,014	3.5	8.0	1,782	49.5 5,700
Betsie River ¹	170	6	14	15,149	3.5	7.0	2,559	68.5 8,183
Total	598	...	...	\$53,091	...	...	8,484	233.5 \$25,997

¹ Bioassay range estimated for TFM.

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A HORIZONTAL SAMPLER FOR COLLECTION OF WATER SAMPLES NEAR THE BOTTOM

The need to obtain adequate water samples immediately above a lake bottom or at a precisely defined depth is not new. The problem is of particular concern in a large section of central Lake Erie, where dissolved oxygen concentration may be reduced to 1 ppm or less in the hypolimnion and where the metalimnion frequently extends to or within 30 or 60 cm of the bottom (Beeton 1963; Carr 1962). It is impossible to sample the hypolimnetic waters satisfactorily with the usual Nansen, Kemmerer, and Frautschy bottles (Carr 1962). Although the 500-ml sampler described here was designed, constructed, and used extensively and successfully to meet the particular problem in Lake Erie, it should be equally useful in a variety of situations.

The sampler (shown in open and closed positions in Fig. 1) is designed to operate in a horizontal position, and thus samples a much narrower stratum of water than the usual water samplers lowered in vertical

position. The weighted messenger that closes most of the samplers now in use is replaced by a solenoid that releases a spring-activated piston and closing valve. A thorough clearing and refilling of the sampler chamber is assured when the mechanism is triggered.

Results of analyses for dissolved oxygen in water collected with the horizontal sampler and with other samplers (Fig. 2) illustrate the usefulness of the new instrument in collecting water immediately above the bottom. The four graphs show typical examples of July temperature-depth profiles recorded on bathythermograph slides, and the amounts of dissolved oxygen in water collected with the new horizontal sampler and with Nansen and Kemmerer bottles, at four stations in Lake Erie. An

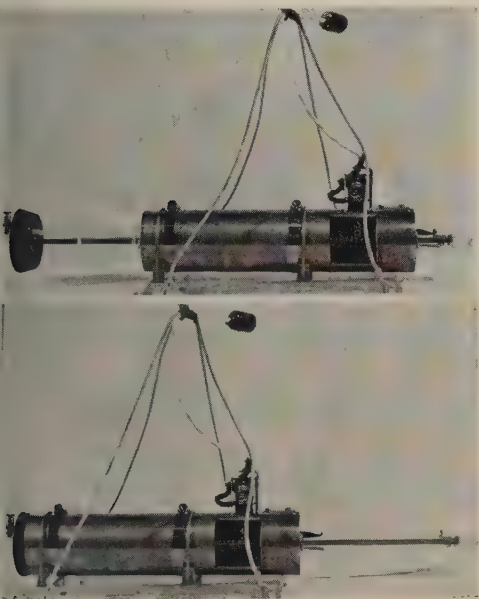


FIG. 1. Horizontal sampler in the open and closed positions.

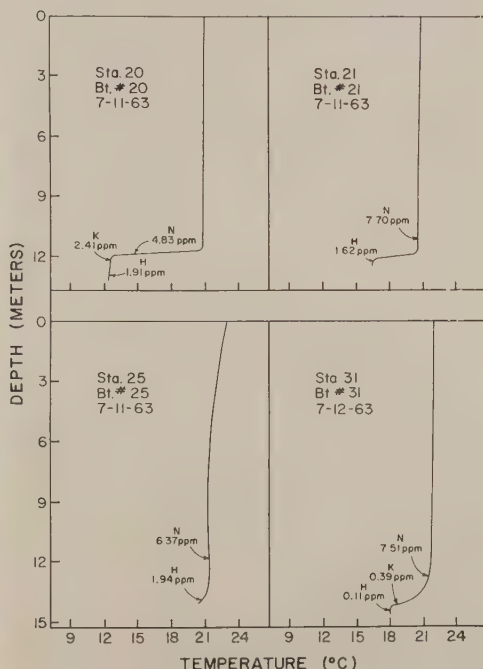


FIG. 2. Bathythermograph traces and dissolved oxygen content of water collected with the Nansen (N), Kemmerer (K), and horizontal (H) water samplers in Lake Erie, July 1963.

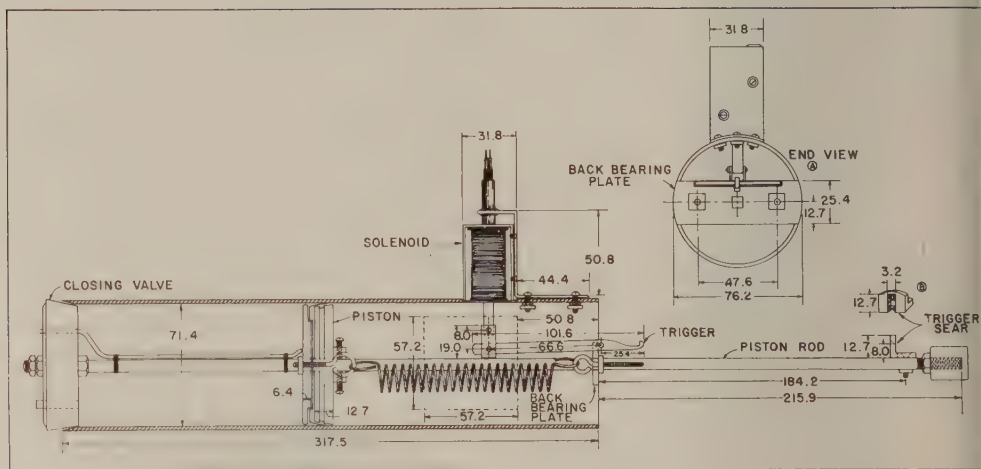


FIG. 3. Detailed drawing of the sampler shown in Fig. 1 (measurements in mm).

arrow indicates the exact depth at which each sample was taken. When the hypolimnion was extremely narrow, water collected by bottles did not show the oxygen deficiency shown in water from the horizontal sampler.

Construction details of the sampler are illustrated in Fig. 3. The basic cylinder is a 317.5-mm (12½-in.) section of brass pipe with a 76-mm (3-in.) outside diameter and 71.4-mm (2⅞-in.) inside diameter. The closing valve attached to the 6.4-mm (¼-in.) square brass piston rod is a beveled, 19-mm (¾-in.)-thick rubber stopper, 76 mm (3 in.) in diameter, backed with a 3.2-mm (⅛-in.)-thick aluminum washer 70 mm (2¾ in.) in diameter. One of the two small holes drilled through the closing valve functions as a drain tube, and the other allows air to enter the upper end of the chamber through a plastic tube as the water sample is withdrawn while the sampler is in a vertical position. Because a wide variety of closing devices for these openings may be used, no specific mechanism is illustrated.

A 70-mm (2¾-in.)-diameter heavy-duty polyethylene snap-on cap from a plastic food container forms a minimum-friction, noncontaminating, watertight seal between the piston and cylinder wall. This cap is placed between two circular pieces of

polystyrene, approximately 67 mm (2⅞ in.) in diameter and 6.4 and 12.7 mm (¼ and ½ in.) thick. The thicker plastic disc is placed on the inner side of the cap so that its tapered edge causes the lip of the cap to be expanded sufficiently to form a seal between the piston and cylinder wall. To ensure further the sealing of this lip or piston ring, a 3.2-mm (⅛-in.) groove is cut around the edge of the inner disc and soft nylon cord (not shown in Fig. 3) is wound around this groove until the desired tension on the piston-sealing ring is obtained. Two 4 × 38-mm (No. 10) eyebolts passing through the piston serve a dual purpose. The threaded portions hold the three sections of the piston together; the eyes are used to attach one end of the two piston-actuating springs to the piston. The opposite end of each spring is attached to the back bearing plate with a similar eyebolt that serves also for adjusting the tension. The lightweight extension springs are 16 mm (⅝ in.) in diameter and 90 mm (3½ in.) long (when under no tension). In addition to furnishing an anchor for the springs, the back bearing plate is used as the rear bearing surface of the piston rod and furnishes a place to anchor the trigger pin. The back plate is permanently attached to the back of the sampler with silver solder. The square hole for the pis-

on rod is centered in the back bearing plate; the small hole on each side of it receives the eyebolts mentioned above (Fig. 3, View A).

The pivot pin of the solenoid trigger is attached to the back bearing plate with lead-tin solder so that it may be removed, if necessary, for final adjustment when the sampler has been completely assembled.

The trigger sear is attached near the end of the piston rod. The top of the sear notch is beveled from 8.0 to 12.7 mm ($\frac{5}{16}$ – $\frac{1}{2}$ in.) on the front side so that the trigger is self-engaging when the sampler is cocked by pushing the piston rod as far forward as possible (Fig. 3, View B). A solenoid (6-v, d-c, 2 ohms, 8 amp) on top of the sampler has its plunger attached to the trigger through a flexible link. The solenoid has an adjustable stroke of 3.2–48.0 mm ($\frac{1}{8}$ – $\frac{3}{4}$ in.) and a maximum lift of 1.1 kg (39 oz). It is saturated thoroughly with Krylon crystal-clear No. 1303 spray coating to protect it from water damage.

The 57.2×57.2 -mm ($2\frac{1}{4} \times 2\frac{1}{4}$ -in.) hole cut in the side of the sampler adjacent to the solenoid plunger and trigger is essential for the assembly, disassembly, and adjustment of the sampler and for the exhaust of water when the sampler is activated.

The hand winch shown in Fig. 4 carries 100 m (300 ft) of two-conductor No. 16 stranded wire. The wire functions both as a cable for lowering and raising the sampler and as an electrical conductor for the solenoid. Power is transmitted from a 6-v battery to the wire on the hand winch via two stationary brushes and insulated sliding rings that are mounted on the left side of the winch drum. (The clear plastic base plate shown in the photographs need not be used. A single bridle may be attached with circular clamps directly to the sampler tube.)

Although this sampler was designed for a specific purpose, it has a wide variety of applications. A sampler of this type may be used singly or in a series as a multilevel sampler (as described for a different instrument by Gleason and Goff 1963). A number of the samplers can be attached to

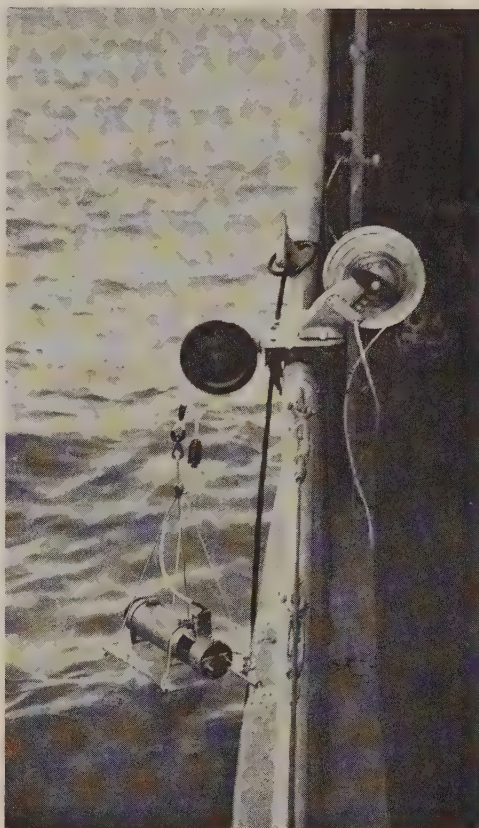


FIG. 4. Horizontal sampler and small hand winch attached to the side of the research vessel *Cisco*, in operating position.

a metal frame of sufficient length to allow spacing at desired intervals and, if properly wired, individual or simultaneous closure at any level between the surface and bottom. If a resistance thermometer is attached to the mounting bracket, individual samplers may be actuated at any desired temperature stratum. With the addition of a suitable temperature and pressure transducer, samplers can be actuated manually or automatically at any desired depths or temperatures. If a timing device is used, a series of samplers may be actuated automatically at predetermined time intervals.

The design of this sampler is such that the dimensions can be increased or decreased considerably without adverse effect.

The diameter of the sample chamber could be reduced by as much as 50% or more to allow sampling of an even narrower stratum of water. The volume could be maintained simply by lengthening the tube, piston rod, and the stroke of the piston.

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DIRECTION OF MOVEMENT OF SALMON IN THE NORTH PACIFIC OCEAN AND BERING SEA AS INDICATED BY SURFACE GILLNET CATCHES, 1959-1960

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Seattle, Washington, September 1962

ABSTRACT

High seas movements of sockeye, chum and pink salmon in the Aleutian area of the North Pacific Ocean and the Bering Sea are described for the period May through August. Included is a brief comparison of movement indicated by gillnet catches with that indicated by purse seine catches from this area.

Gillnet catches showed a similar direction of movement for each species where taken together in the North Pacific; this direction of movement was predominantly westward. Dominant sockeye salmon movements in the Bering Sea were eastward and northward, whereas the movements of chum and pink salmon were westward and northward.

Direction of movement indicated by gillnet catches in 1959 and 1960 compared with movement indicated by purse seine catches in 1956, 1957 and 1958 shows a general similarity in most of the Aleutian area, particularly in the North Pacific.

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INTRODUCTION

Salmon (*Oncorhynchus* spp.) have been gillnetted in offshore waters of the North Pacific Ocean and Bering Sea by the U.S. Bureau of Commercial Fisheries for the International North Pacific Fisheries Commission (INPFC) each year since 1955. Among objectives of this sampling program is that of determining the distribution in time and space of sockeye, chum and pink salmon. Information on the direction of movement of salmon captured in the gillnets is pertinent to the study of their distribution and should contribute to the determination of migration routes in the Aleutian waters.

This report deals with the direction of movement of sockeye (*O. nerka*), chum (*O. keta*) and pink salmon (*O. gorbuscha*) during the 1959 and 1960 seasons in the Aleutian area of the North Pacific Ocean and Bering Sea as indicated by offshore surface gillnet catches and includes a brief comparison with purse seine catches of 1956, 1957 and 1958 from this same general area.

PROCEDURES

Direction data were obtained in conjunction with other catch data obtained at each gillnet set, but, because direction data are greatly affected by certain variables, particularly weather, only comparable catches could be utilized. Criteria used for determining comparable (usable) catches are given along with certain assumptions which were made in determining direction of movement.

DATA COLLECTION

In the Aleutian area, the fishing was from May 20 until August 12 in 1959 and from May 18 until

August 26 in 1960. Surface gillnets were fished from chartered halibut schooners, the MV *Pioneer* and MV *Tordenskjold* in 1959, and the MV *Paragon* and MV *Pioneer* in 1960.

Nets were fished in a string which consisted of four standard (INPFC) mesh sizes fished in the following ratio: twenty-four $4\frac{1}{2}$ -inch nets and four each of the $5\frac{1}{4}$ -inch, $3\frac{1}{4}$ -inch and $2\frac{1}{2}$ -inch sizes. Twenty-four nets were arranged in a $4\frac{1}{2}$ -inch, $5\frac{1}{4}$ -inch, $4\frac{1}{2}$ -inch, $3\frac{1}{4}$ -inch, $4\frac{1}{2}$ -inch, $2\frac{1}{2}$ -inch sequence repeated four times with 12 additional $4\frac{1}{2}$ -inch nets attached at the end of the string. Each net was 50 fathoms in length and approximately 25 feet deep. Thirty-six nets were fished in 70 of 76 sets during 1959 and in 78 of 82 sets during 1960. Twenty-four nets were fished in each of the other sets.

The nets were constructed entirely of nylon materials with the exception that some cotton lead lines were used; color ranged from medium to dark grey-green. Additional details of gear, set and haul procedures and the usual catch data collections are given by Hanavan and Tanonaka (1959).

Each time the nets were fished the direction of net lay was recorded (1) when the net string was set out in the evening, and (2) when hauled aboard in the morning. Direction of net lay is defined as the two compass points, e.g., N-S, fixing the line formed by the string of nets when fishing. It was necessary while hauling to obtain the definite lay of each shackle of net, since often the far end of the string could not be seen from the vessel, and the nets frequently were lying in an irregular pattern as the result of wind and ocean currents. During the net hauling operations, as fish were picked from the nets, their entry direction was recorded and later corrected to the compass bearing at a 90 degree angle to the direction of the lay of the net.

Maturity determinations of sockeye and chum salmon were made of all or a sample of each catch in 1959 and of all the catches in 1960 with the exception of (1) catches in excess of 300 fish from which representative samples of at least 300 fish were taken, and (2) mutilated fish from which gonads were not available. Maturity of the 1959 catches was determined in the laboratory, but maturity of a portion of most 1960 catches was determined aboard ship and the remainder in the laboratory. In either case, maturity determinations were based upon the method of Ishida and Miyaguchi (1958), i.e., for fish taken in May and after, testes weight of two grams or more or ovary weight of 20 grams or more (both ovaries) indicates fish maturing in the year caught. In the laboratory

actual gonad weights were taken; however, aboard ship maturity determinations were made primarily by visual examination of the gonads after the observer first had gained experience at recognition of the size of "mature" and "immature" gonads. Actual shipboard classification as to maturity was made only when the observer was certain of the gonad development. This may have resulted in a slightly higher percentage of immatures, particularly chums, since those of borderline size may have been from fish which would have matured later in the year.

CRITERIA FOR COMPARABLE CATCHES

Ocean currents and wind changes at times swung the nets and vessel to such an extent it was impossible to determine even a general direction of fish movement from a particular set. Also, weather conditions at the time the nets were retrieved influenced to some extent the accuracy of observations and the recording of these observations. Since currents, wind and weather could not be controlled, nor their influence on the accuracy of observations assessed, only comparable sets under the following criteria were considered: (1) Single night sets; (2) Sets in which swing of the entire string did not exceed 90 degrees and the position of the individual shackles within the string did not vary by more than 90 degrees; (3) Catches of at least 20 fish of a single species. To reduce congestion in the illustrations which indicate direction of movement, smaller catches were not used. Examination of catches of five to 19 fish showed that the direction of movement in most of these catches was similar to larger catches made nearby.

Dominance of the catch from one side of the nets or the other requires mention even though it is not one of the above criteria. Experience suggests that under certain conditions, such as severe weather or large catches, direction error approaches 10 percent as a result of human error in observation and recording. Catches which show a dominance of 60 percent or more from one side of the nets are therefore considered to be more reliable indicators of direction of movement than those showing a more nearly equal percentage from each side. On the other hand, accurately recorded catches which show nearly equal numbers of fish entering from each side of the net may indicate a movement parallel to the net lay or a random movement in the immediate area where the nets are set. Since the nature of these records does not permit a precise determination of direction, catches of less than 60 percent dominance in direction are not employed in ascertaining the probable movement of salmon caught. Usable catches having at least a 60 percent dominance in direction included

78 percent of all catches in 1959, 85 percent of all catches in 1960 and 81 percent of all catches for the combined years.

DETERMINING DIRECTION

In determining the direction of fish movement of each catch from net lay at set and haul, the "average" net lay was used. Average net lay was considered to be the midpoint of swing of the net string with the vessel as the pivot. From this average net lay, the nearest of the eight main compass points (i.e., North, Northeast, East, Southeast, South, Southwest, West and Northwest) was chosen.

A compass point perpendicular to the average net lay was assumed to represent the general direction a majority of the fish were moving in a particular catch. This assumption was made because of the large angle, perhaps nearly 180° , from which fish can enter the net from either side.

Most salmon in Aleutian waters spawn in streams of either Asia or North America exclusive of the Aleutian Islands. Therefore, migration of maturing fish from these waters ultimately must be more or less westward or eastward toward the major continental spawning areas. North-south sets for this reason were believed to be the most effective in determining and clarifying the major movements. In practice this was not always possible because the string of nets had to be set approximately downwind to hold the vessel free while drifting overnight. These sets made in other than a north-south direction thus provided some information on various directions of movement for immature as well as maturing salmon.

The direction in which the nets were set influenced the interpretation of direction data. For example, a catch of fish moving northwest would be interpreted as moving west when caught in a string of nets set north-south or interpreted as moving north in a string of nets set east-west. Several sets in the same proximity were therefore necessary to provide a more reliable indication of the direction of movement than a single set could provide in the large ocean areas. Since sets were usually made in a north-south direction, the interpretation of these data therefore was somewhat biased toward either a westward or an eastward direction of movement.

Direction of movement data from gillnets, while not so precise as direct observation of live fish, does provide considerable information on the general movements of salmon.

RESULTS

CATCH

Seventy-six gillnet sets during the 1959 season produced catches of salmon (sockeye, chum and pink only) ranging from two to 1,431, and totaling 21,092 fish, as compared to 83 sets in 1960 with catches ranging from four to 1,334, but totaling only 16,179 fish (INPFC, 1960, 1961). The main difference in total catch was the marked reduction in the number of pink salmon in 1960. The area covered in 1959 was roughly bounded by latitudes 60°N. and 47°N. and longitudes 171°E. and 160°W. Coverage in 1960 shifted slightly southward, but was approximately the same as in 1959. The patterns of the total number of gillnet sets in 1959 and 1960 are shown in the annual reports of the International North Pacific Fisheries Commission for those years. There were 49 sockeye, 53 chum and 33 pink salmon catches in 1959 and 48 sockeye, 50 chum and 16 pink salmon catches in 1960 which provided usable direction data.

Usable data in Tables 1 to 4 were plotted separately for May-June and July-August catches. Figures 1 to 4, 7 to 10 and 13 to 16 show these plots with the percentage of dominant direction of movement indicated. Catches of 50 or more fish are represented by a heavy arrow and those of from 20 to 49 fish by a light arrow and are referred to as "large" and "small" catches, respectively. Similarly, Figures 5 and 6, 11 and 12, and 17 and 18 show the dominant direction of movement with 1959 and 1960 plotted together but with percentage figures omitted for clarity.

MATURITY

Sockeye Salmon.

A seasonal change in the maturity composition of the sockeye salmon catch in the Aleutian area was quite evident in both 1959 and 1960 (Table 5). The total catch was composed mostly of mature fish during May and June (1959, 93 percent; 1960, 90 percent) and mostly of immature fish during July and August (1959, 84 percent; 1960, 86 percent). (Mature, here, refers to those fish which would have spawned during the year caught.) That portion of the total catch providing usable direction data shows a similar maturity composition, within plus or minus five percent, compared to the total catch. Individual catches, too, show a dominance of matures in May and June and immatures in July and August. Some exceptions were noted each year, usually in late

TABLE 1. Direction of movement of salmon as indicated by gillnet catches of the MV *Pioneer*, 1959.

Set no.	Date	Position of set		Sockeye		Chum		Pink	
		Lat. N.	Long.	Number	Percent ²	Number	Percent ²	Number	Percent ²
1	4/23-4/24	56°01'	152°59'W	1N		1S			
2	4/24-4/27	55°00'	153°00'W	16?		7?			
3	5/19-5/20	51°29'	175°03'E	11N-14S	56S	143N-39S	79N		
4	5/21-5/22	51°00'	175°00'E	15S-26N	64N	165S-253N	61N		
5	5/22-5/23	50°00'	175°00'E	11N-6S		35N-7S	85N		
6	5/23-5/24	49°00'	175°00'E	18N-10S	64N	125N-52S	73N		
7	5/24-5/25	48°00'	175°00'E	28N-7S	80N	326N-162S	67N	86N-16S	85N
8	5/26-5/27	49°38'	171°44'E	17N-10S	63N	12N-25S	68S		
9	5/27-5/28	50°25'	171°20'E	12NE-10SW	54NE	3NE-16SW			
10	6/2-6/3	52°00'	171°00'E	13N-2S		10N-1S			
11	6/3-6/4	52°47'	171°00'E	12N-4S		12N-8S	60N	3N-1S	
12	6/4-6/5	53°30'	171°00'E	31N-5S	86N	18N-7S	72N		
13	6/5-6/6	54°20'	171°00'E	49NE-6SW	89NE	8NE-7SW			
14	6/6-6/8	55°00'	171°00'E	21W-42E	^a	12W-6E		1E	
15	6/12-6/13	53°30'	180°	61NW-7SE	90NW	47NW-9SE	84NW	41NW-3SE	93NW
16	6/21-6/22	52°38'	178°47'W	25SE-27NW	54NW	3SE-13NW		19SE-50NW	72NW
17	6/22-6/23	52°59'	179°55'E	5SE-78NW	94NW	10SE-114NW	92NW	58SE-557NW	91NW
18	6/23-6/24	54°00'	180°	15E-5W	75E	1E-22W	96W	33E-256W	89W
19	6/24-6/25	55°00'	180°	43E-14W	75E	6E-9W		24E-186W	89W
20	6/25-6/26	56°00'	180°	159N-6S	96N	23N-16S	59N	11N-25S	69S
21	6/26-6/27	57°00'	180°	127NE-11SW	92NE	63NE-40SW	61NE	33NE-42SW	56SW
22	6/27-6/28	58°00'	180°	32N-12S	73N	90N-15S	86N	1045N-237S	81N
23	6/29-6/30	60°00'	180°	32N	100N	119N-1S	99N	390N-3S	99N
24	7/4-7/5	58°00'	175°00'E	60N-8S	88N	146N-4S	97N	755N-9S	99N
25	7/14-7/15	55°00'	175°00'E	19N		15S-83N	85N	74S-490N	87N
26	7/15-7/16	54°00'	175°00'E	6SW-4NE		17SW-17NE	50NE	10SW-14NE	58NE
27	7/18-7/19	51°54'	174°06'E	16N-8S	67N	15N-5S	75N	10N-1S	
28	7/21-7/22	51°30'	175°00'E	32SW-26NE	^a	4SW-2NE		3SW	
29	7/22-7/23	50°30'	175°00'E	42W-15E	74W	8W-3E		3W	
30	7/26-7/27	51°31'	176°42'W	387SW-88NE	^a	136SW-28NE	^a	33SW-4NE	^a
31	7/27-7/28	51°31'	176°40'W	101W-73E	58W	42W-24E	64W	2W-3E	
32	7/28-7/29	51°29'	176°38'W	168NE-339SW	67SW	53NE-144SW	73SW	22NE-17SW	56NE
33	8/4-8/5	51°00'	175°00'W	47N-320S	87S	2N-12S			
34	8/5-8/6	50°00'	175°00'W	157NW-201SE	56SE	62NW-53SE	54NW	1NW-2SE	
35	8/6-8/7	49°00'	175°00'W	17SW-11NE	61SW	44SW-34NE	56SW		
36	8/8-8/9	48°00'	175°00'W	1NE		11SW-18NE	62NE		
37	8/11-8/12	49°05'	170°10'W	1W		5E-22W	82W	1E	

¹ Heading direction of salmon. (Net lay direction of usable catches was approximately perpendicular to the heading direction shown.)

² Percentage of dominant direction—usable catches only.

³ Net turned during set—direction estimated.

June or early July, although in May 1960 fish caught south of 48°N. were immature.

In view of the rather sharp separation of mature and immature sockeye salmon catches in 1959 and 1960, it is evident that the direction of movement presented here is essentially that of matures through May and June and that of immatures through July

and August. In the few catches where both matures and immatures were taken in number (20 or more), four catches (Table 6) do provide some evidence that direction of movement differed with maturity at a certain location and time. However, this difference in movement was only apparent in 1960 and only from a relatively small area, roughly 4,000 square miles, south of the east-central Aleutians.

TABLE 2. Direction of movement of salmon as indicated by gillnet catches of the MV *Tordenskjold*, 1959.

Set no.	Date	Direction by species ¹							
		Position of set		Sockeye		Chum		Pink	
		Lat. N.	Long.	Number	Percent ²	Number	Percent ²	Number	Percent ²
1	5/24–5/25	53°17'	165°35'W	2NE–6SW		5NE–53SW	91SW	2NE–4SW	
2	5/25–5/26	52°40'	167°37'W	1SW		1NE–35SW	97SW		
3	5/26–5/27	51°56'	169°39'W	7NE–48SW	87SW	3NE–8SW		4NE–5SW	
4	5/27–5/28	51°41'	171°57'W	61S–17N	³	24N–7S	³	10S–5N	
5	6/1–6/2	51°00'	180°	99W–9E	92W	117W–34E	78W	9W–1E	
6	6/2–6/3	49°59'	179°57'W	15W–8E	65W	77W–17E	82W	7W–3E	
7	6/3–6/4	49°03'	179°56'W	9E–10W		37E–73W	66W	36E–109W	75W
8	6/6–6/7	49°01'	175°04'W	7S–15N	68N	12S–34N	74N	28S–63N	69N
9	6/11–6/12	51°32'	176°31'W	106E–144W	58W	10E–45W	82W	24E–42W	64W
10	6/13–6/14	51°32'	176°34'W	20N–33S	62S	9N–6S		13N–9S	59N
11	6/14–6/15	51°31'	176°25'W	132E–159W	54W	36E–81W	69W	36E–106W	75W
12	6/20–6/21	52°59'	175°00'W	32W–6E	84W	26W–13E	69W	170W–55E	76W
13	6/21–6/22	54°00'	176°00'W	29W–80E	³	17W–28E	³	154W–28E	³
14	6/22–6/23	55°00'	176°00'W	17W–79E	82E	33W–5E	87W	760W–96E	89W
15	6/23–6/24	56°00'	176°00'W	41W–64E	³	22W–6E	³	130W–27E	³
16	6/24–6/25	57°00'	175°00'W	22S–97W	82N	5S–5N		18S–11N	62S
17	6/26–6/27	59°00'	170°00'W	55E–4W	93E	42E–5W	89E	67E–23W	74E
18	6/27–6/28	58°00'	170°00'W	7W–62E	90E	1W–10E		1W–3E	
19	6/28–6/29	56°56'	170°06'W	3W–2E					
20	6/29–6/30	55°59'	170°00'W	21W–181E	³	35W–28E	³	62W–17E	³
21	6/30–7/1	55°01'	170°03'W	4W–13E		7W–11E		8W–4E	
22	7/1–7/2	53°58'	170°01'W	10W–11E	52E	25W–7E	78W	60W–10E	86W
23	7/2–7/3	53°18'	170°00'W	2W–13E		29W–24E	55W	115W–45E	72W
24	7/3–7/4	52°00'	169°53'W	201SW–38NE	84SW	77SW–11NE	87SW	86SW–35NE	71SW
25	7/4–7/5	51°00'	169°56'W	67W–11E	86W	48W–11E	81W	159W–30E	84W
26	7/10–7/11	53°30'	165°00'W	386W–74E	84W	423W–108E	80W	38W–26E	59W
27	7/11–7/12	52°58'	164°56'W	283W–30E	90W	26W–3E	90W	12W–11E	52W
28	7/12–7/13	52°00'	165°00'W	171SW–28NE	86SW	33SW–15NE	69SW	8SW–5NE	
29	7/14–7/15	50°02'	165°00'W	8SE–30NW	³	90SE–334NW	³	3SE	
30	7/15–7/16	49°02'	165°00'W	4W–1E		147W–21E	88W		
31	7/16–7/17	48°01'	165°05'W	3W–3E		41W–7E	85W		
32	7/18–7/19	47°01'	160°02'W	1E		13E–53W	80W	1E	
33	7/19–7/20	48°02'	160°00'W	5E		18E–28W	61W	1W	
34	7/20–7/21	49°02'	160°00'W	6E–14W	70W	31E–35W	53W		
35	7/21–7/22	49°55'	160°05'W	15S–47N	76N	110S–72N	60S	6S–6N	
36	7/22–7/23	50°57'	159°55'W	51S–86N	62N	37S–96N	72N	7S–25N	78N
37	7/23–7/24	51°57'	159°58'W	167SE–127NW	57SE	26SE–32NW	55NW	8SE–15NW	65NW
38	7/24–7/25	53°00'	160°00'W	22E–44W	67W	101E–215W	68W	45E–72W	65W
39	7/25–7/26	53°55'	159°40'W	29E–40W	58W	21E–39W	65W	44E–37W	54E

¹ Heading direction of salmon. (Net lay direction of usable catches was approximately perpendicular to the heading direction shown.)

² Percentage of dominant direction—usable catches only.

³ Net turned during set—direction estimated.

Chum Salmon.

Cursory examination of maturity data from 1960 high seas catches of chum salmon indicates a maturity composition similar to that of sockeye salmon catches by season (i.e., catches were mostly mature fish in May and June and mostly immatures in July and August). The proportion of immature chum in

July–August catches appears to be generally lower than for sockeye salmon in the same catch. However, observers did note distinct difficulty in visually determining the maturity of gonads of many of the large chum (over 50 cm.) taken during the July–August period. Small, definitely immature, fish usually dominated the July–August catches, however. Examination of unpublished maturity data and per-

TABLE 3. Direction of movement of salmon as indicated by gillnet catches of the MV *Paragon*, 1960.

Set no.	Date	Position of set		Sockeye		Chum		Pink	
		Lat. N.	Long.	Number	Percent ²	Number	Percent ²	Number	Percent ²
1	5/17-5/18	52°50'	167°00'W	4W-2E		7W-9E		1W-1E	
2	5/18-5/19	52°25'	168°31'W	1W		35W-9E		1W-1E	
3	5/21-5/22	52°00'	169°59'W	2NW-3SE		36NW-9SE	80NW		
4	5/22-5/23	51°04'	170°49'W	147N-88S	³	52N-11S	³	19N-4S	³
5	5/23-5/24	50°06'	171°40'W	50NW-44SE	53NW	20NW-2SE	91NW	11NW-9SE	55NW
6	5/26-5/27	47°03'	174°10'W	4NW		68NW-18SE	79NW	32NW-9SE	78NW
7	5/27-5/28	46°00'	174°59'W	10W-4E		15W-1E		18W-3E	86W
8	5/28-5/29	45°00'	175°00'W	55W-5E	92W	4W		5W-1E	
9	5/30-5/31	47°00'	177°11'W	2E-2W		18E-55W	75W	3E-18W	86W
10	5/31-6/1	47°44'	177°46'W	1W-14E		27W-16E	63W	6W-3E	
11	6/3-6/4	49°01'	180°	4W-2E		24W-43E	64E	2W-6E	
12	6/4-6/5	50°02'	179°59'E	35W-16E	³	77W-17E	³	8W-1E	
13	6/5-6/6	51°00'	179°59'E	82E-264W	76W	21E-157W	88W	2E-25W	93W
14	6/6-6/7	51°04'	178°30'W	31E-143W	82W	6E-20W	77W	3E-2W	
15	6/14-6/15	53°00'	176°10'W	127W-151E	54E	7W-8E		24W-11E	69W
16	6/15-6/16	54°01'	175°38'W	50NW-232SE	82SE	12NW-8SE	60NW	7NW-2SE	
17	6/16-6/17	55°00'	175°01'W	6NW-2SE		8NW-1SE		13NW-1SE	
18	6/17-6/18	56°01'	175°00'W	15W-52E	78E	10W-8E		13W-2E	
19	6/18-6/19	57°01'	174°59'W	18SE-53NW	75NW	1SE-64NW	98NW	13SE-68NW	84NW
20	6/19-6/20	56°42'	173°27'W	232E-48W	³	32E-39W	³	5E-7W	
21	6/20-6/21	56°21'	171°41'W	99E-70W	59E	11E-47W	81W	1E-1W	
22	6/21-6/22	55°58'	169°59'W	52W-207E	³	4W-9E			
23	6/22-6/23	55°00'	170°01'W	21W-80E	79E	4W-7E		2W	
24	6/23-6/24	54°00'	169°59'W	26SE-170NW	³	36SE-162NW	³	3SE-11NW	
25	6/24-6/25	53°20'	169°59'W	143NW-52SE	³	71NW-23SE	³	4NW-1SE	
26	6/25-6/26	52°15'	169°57'W	41NW-57SE	58SE	95NW-70SE	58NW	6NW-6SE	
27	6/26-6/27	51°18'	170°37'W	34NE-49SW	59SW	14NE-42SW	75SW	1NE-1SW	
28	6/27-6/28	50°07'	171°43'W	60W-41E	59W	57W-32E	64W	9W	
29	6/28-6/29	49°05'	172°31'W	15SW-4NE		65SW-39NE	62SW	1SW	
30	7/6-7/7	53°44'	173°00'W	22W-37E	63E	15W-27E	63E	2W-1E	
31	7/7-7/8	53°26'	173°01'W	10W-16E	62E	16W-4E	80W	1E	
32	7/8-7/9	53°06'	173°01'W	1W-1E		2W			
33	7/10-7/11	51°29'	173°04'W	111W-72E	61W	11W-6E		3E	
34	7/11-7/12	51°09'	173°01'W	83W-31E	73W	8W-3E		1W-2E	
35	7/12-7/13	50°50'	172°59'W	52W-20E	72W	43W-8E	84W	10W-1E	
36	7/14-7/15	50°29'	173°00'W	21W-12E	64W	49W-8E	86W	15W-3E	
37	7/16-7/17	50°29'	170°00'W	32E-38W	54W	10E-43W	81W	15E-10W	60E
38	7/17-7/18	50°54'	170°02'W	122E-110W	³	34E-85W	³	11E-19W	³
39	7/18-7/19	51°13'	170°02'W	93W-39E	³	39W-24E	³	14W-9E	³
40	7/19-7/20	51°32'	170°01'W	65NW-73SE	53SE	33NW-39SE	54SE	11NW-4SE	
41	7/20-7/21	51°51'	169°59'W	204W-102E	67W	448W-161E	74W	58W-20E	74W
42	7/22-7/23	52°15'	170°00'W	60W-29E	67W	412W-129E	76W	45W-18E	71W
43	7/24-7/25	53°05'	166°05'W	24W-19E	56W	1050W-165E	87W	43W-33E	56W

¹ Heading direction of salmon. (Net lay direction of usable catches was approximately perpendicular to the heading direction shown.)

² Percentage of dominant direction—usable catches only.

³ Net turned during set—direction estimated.

TABLE 4. Direction of movement of salmon as indicated by gillnet catches of the MV *Pioneer*, 1960.

Set no.	Date	Direction by species ¹							
		Position of set		Sockeye		Chum		Pink	
		Lat. N.	Long.	Number	Percent ²	Number	Percent ²	Number	Percent ²
1	5/27–5/28	50°07'	170°04'E	24E–36W	60W	4E–17W	81W	1W	
2	5/28–5/29	51°00'	170°00'E	6SE–6NW		3SE–11NW		31NW	100NW
3	5/29–5/30	52°00'	170°00'E	7SE–29NW	81NW	6SE–90NW	94NW	1SE–22NW	96NW
4	5/30–5/31	53°02'	170°00'E	4SW–27NE	87NE	2SW–19NE	90NE	1SW–5NE	
5	6/4–6/5	54°03'	171°04'E	7SE–4NW		3SE–44NW	94NW	3SE–7NW	
6	6/5–6/6	53°58'	172°46'E	5E–6W		4E–10W		2E–3W	
7	6/6–6/7	53°48'	174°13'E	7E–1W		4E		1E–10W	
8	6/7–6/8	53°37'	175°54'E	37NE–4SW	90NE	67NE–3SW	96NE	33NE–4SW	89NE
9	6/8–6/9	53°14'	178°08'E	4SE–1NW		3SE–14NW		4SE–11NW	
10	6/9–6/10	52°52'	179°51'W	2SE–6NW		3SE–6NW		1SE–3NW	
11	6/10–6/11	52°24'	178°00'W	28?		18?			
12	6/17–6/18	53°00'	176°58'W	8SW–116NE	³	12NE		4SW–7NE	
13	6/18–6/19	54°03'	177°05'W	198E–9W	96E	15E–15W	50W	1E	
14	6/19–6/20	55°01'	176°58'W	130E–6W	94E	29E–8W	78E	2E	
15	6/20–6/21	55°00'	178°52'W	14NW–10SE	58NW	74NW–15SE	83NW	58NW–7SE	89NW
16	6/22–6/23	54°57'	179°23'E	3SW–39NE	93NE	4SW–1NE		5SW	
17	6/24–6/25	54°59'	174°57'E	7N–2S		24N–6S	80N	26N–8S	77N
18	6/26–6/27	53°00'	175°00'E	11NW–1SE		171NW–53SE	76NW	18NW–1SE	
19	6/28–6/29	50°59'	174°55'E	71NW–20SE	78NW	45NW–13SE	78NW	4NW–1SE	
20	6/29–6/30	50°01'	175°03'E	76NW–32SE	70NW	15NW		4NW–1SE	
21	7/1–7/2	49°01'	179°56'W	19N–3S	86N	19N–3S	86N		
22	7/2–7/3	50°02'	178°36'W	41W–13E	76W	28W–3E	90W	2W	
23	7/3–7/4	51°20'	176°45'W	61SW–34NE	64SW	29SW–36NE	55NE	2SW–1NE	
24	7/13–7/14	53°18'	173°12'E	26N–4S	87N	32N–18S	64N		
25	7/15–7/16	52°22'	172°50'E	180W–37E	83W	76W–19E	80W	1W–1E	
26	7/16–7/17	52°00'	173°00'E	79W–16E	83W	55W–22E	71W	2W	
27	7/17–7/18	51°39'	173°02'E	116NW–23SE	83NW	100NW–12SE	89NW	2NW	
28	7/18–7/19	51°20'	173°00'E	61NW–12SE	84NW	13NW–1SE			
29	7/26–7/27	51°20'	178°00'E	90N–62S	59N	50N–24S	68N	12N–1S	
30	7/27–7/28	51°00'	178°00'E	84N–254S	70S	13N–14S	52S	3N–1S	
31	7/28–7/29	50°39'	178°02'E	86NE–158SW	66SW	8NE–25SW	76SW	1SW	
32	7/29–8/1	50°20'	178°00'E	149NW–76SE	³	23NW–8SE	³	1SE	
33	8/13–8/14	51°28'	176°30'W	67NW–351SE	84SE	52NW–33SE	61NW	4SE	
34	8/16–8/17	51°00'	176°30'W	76N–186S	71S	28N–70S	71S		
35	8/17–8/18	50°40'	176°30'W	41NW–212SE	84SE	16NW–77SE	83SE		
36	8/18–8/20	50°20'	176°30'W	147S–88N	³	28S–8N	³	1N	
37	8/23–8/24	52°43'	159°58'W	2W		18W–21E	54E		
38	8/24–8/25	53°15'	160°00'W	3W–3E		12W–15E	56E	1E	
39	8/25–8/26	54°17'	160°00'W	4SE		1NW–5SE		1NW–2SE	

¹ Heading direction of salmon. (Net lay direction of usable catches was approximately perpendicular to the heading direction shown.)

² Percentage of dominant direction—usable catches only.

³ Net turned during set—direction estimated.

sonal observation of gillnet catches during the 1956 to 1959 seasons corroborate this impression that maturity of chum catches was generally similar to that of sockeye catches at the same time and location.

Although it is not now possible to cite specific maturity data with regard to direction of movement,

it can be stated that the direction of movement presented for chum salmon is essentially that of mature fish in May and June and of immatures in July and August.

Pink Salmon.

All pink salmon caught were mature.

TABLE 5. Maturity of the total sockeye salmon catch compared with that portion providing usable direction data, by season, 1959 and 1960.

Season	Year	Catch	Total catch			Direction catch			
			Number examined	Mature		Catch	Number examined	Mature	
				Number	Percent			Number	Percent
May-June	1959	2768	2178	2031	93	2127	1672	1538	92
July-August	1959	4198	2013	313	16	3542	1654	242	15
Total	—	6966	4191	2344	—	5669	3326	1780	—
May-June	1960	4236	3992	3575	90	2880	2541	2197	86
July-August	1960	4363	3844	526	14	3462	3105	466	15
Total	—	8599	7836	4101	—	6342	5646	2663	—

TABLE 6. Contrast in direction of movement of mature sockeye salmon compared to immatures in the same catch.

Set no. ¹	Mature		Immature	
	No. of fish by direction	Dominant direction (percent)	No. of fish by direction	Dominant direction (percent)
27	25NE-18SW	58NE	9NE-23SW	72SW
33	20W-32E	62E	66W-32E	67W
40	30NW-21SE	59NW	28NW-40SE	59SE
41	15W-28E	67E	162W-55E	75W

¹ MV *Paragon*, 1960 (see Table 3 for locations).

DIRECTION OF MOVEMENT

Sockeye Salmon, 1959.

May-June. North Pacific catches during May and June (Fig. 1) show that the predominant movement of sockeye salmon was northward with some indication of westward movement. Catches west of 180° indicated a northward direction of movement, whereas the movement on 180° was westward and variable elsewhere. A single catch near Adak Island indicated a southward movement.

In the Bering Sea during May and June, the majority of catches show either a northward or an eastward directional movement component; most catches were between 175° W. and 180° longitude. Three catches nearest the central Aleutians show westward and northwestward movement in contrast to the dominant directions of movement.

July-August. Catches during July and August (Fig. 2), due to a concentration of fishing effort, were almost entirely from the North Pacific and show a dominant southwestward to westward movement by 71 percent of the catches. Somewhat in contrast, a catch on 175° W. indicated southward and two catches on 160° W. indicated northward movement.

A single catch in the Bering Sea (175°E.) indicated northward movement.

Sockeye Salmon, 1960.

May-June. Catches in the May-June period from the North Pacific (Fig. 3) show the main movement as westward to northwestward. One of these catches was nearly 500 miles south of the Aleutian Chain.

Bering Sea catches of sockeye salmon in May and June show the dominance of a general eastward movement; seven of eight catches indicated north-eastward, eastward or southeastward movement. A contrasting northwestward movement was shown by a single catch. Most catches were located near or between 175° W. and 180° longitude.

July-August. North Pacific catches of sockeye salmon during July and August (Fig. 4) showed westward or northwestward movement east of 175° W. and west of 175° E. in each of 10 catches; these closely spaced catches, most at 20 mile intervals, pointed out the apparent similarity of movement near shore and offshore at some points along the Aleutian Chain. Between 175° W. and 175° E. eight catches indicated five different directions of movement, although catches nearest the Aleutians did show a general southward movement ranging between south-eastward and southwestward.

Turbulent hydrographic conditions encountered immediately south of the central Aleutians (175° W.-180°) and the resulting difficulty in determining direction of net lay no doubt contributed to the apparent variation in movement shown in this area, particularly in July and August 1960. To what extent turbulent hydrographic conditions, such as tidal currents and eddies, affected movement of fish is unknown, but some effects on the gillnet string were observed, namely, irregular net lay and at times tangled nets.

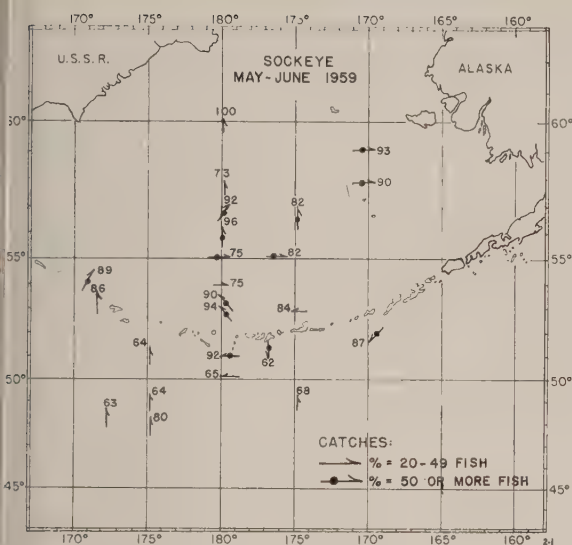


FIGURE 1. Dominant direction of movement of sockeye salmon indicated from gillnet catches of the *Pioneer* and *Tordenskjold* during May and June 1959. Numbers are percentage of catch. Catches were composed mostly of mature fish.

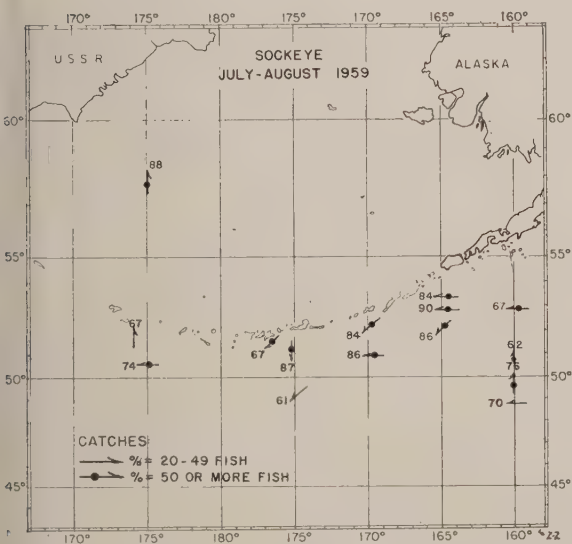


FIGURE 2. Dominant direction of movement of sockeye salmon indicated from gillnet catches of the *Pioneer* and *Tordenskjold* during July and August 1959. Numbers are percentage of catch. Catches were composed mostly of immature fish.

The two catches in the eastern Bering Sea during July and August indicated an eastward movement; these were adjacent catches on 173°W. near the Aleutian Chain. A third catch immediately north of Attu Island showed northward movement.

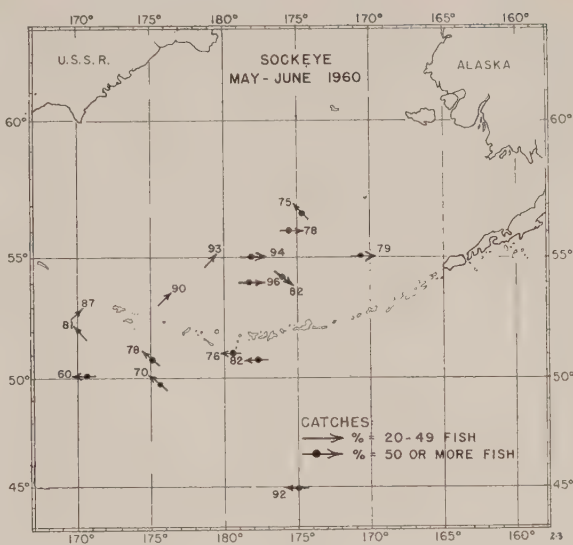


FIGURE 3. Dominant direction of movement of sockeye salmon indicated from gillnet catches of the *Paragon* and *Pioneer* during May and June 1960. Numbers are percentage of catch. Catches were composed mostly of mature fish.

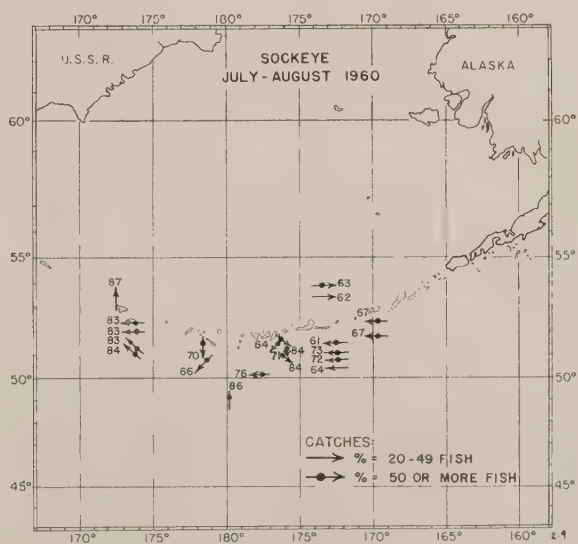


FIGURE 4. Dominant direction of movement of sockeye salmon indicated from gillnet catches of the *Paragon* and *Pioneer* during July and August 1960. Numbers are percentage of catch. Catches were composed mostly of immature fish.

Sockeye Salmon, 1959 and 1960.

May-June. Dominant movement direction during May and June (Fig. 5) was westward along the central Aleutians changing to a dominance of northward

movement south of the western Aleutians with indications of northward and eastward movement in the Bering Sea. The eastward movement in the Bering Sea was most pronounced in the 1960 season.

July-August. July and August catches (Fig. 6) show movement that was generally westward; nearly all fishing effort was concentrated in the North Pacific Ocean in both years. Fishing effort shifted from the eastern and central Aleutians in 1959 to the central and western Aleutians in 1960, and in 1960 adjacent catches near the central Aleutians area, particularly between 175° W. and 178° E., showed considerable variation in direction of movement. This may have been an area of variable movement, but apparent variation was likely due to inaccuracy in determining direction of net lay caused by turbulent hydrographic conditions. Actual movement may well have been westward as indicated by Hartt (1962).

Chum Salmon, 1959.

May-June. The direction of movement of chum salmon in the North Pacific during May and June (Fig. 7) was predominantly westward or northward. Movement shown by most catches in the eastern and central Aleutians, both near shore and offshore, paralleled the general contour of the Aleutian Chain, but in the western Aleutians a northward movement was evident.

Bering Sea catches in May and June indicated a westward and northwestward movement near the Aleutian Chain to 55° N., but northward and northeastward movement to 60° N. Most catches were located along 180° longitude.

July-August. Catches of chum salmon from the North Pacific during July and August (Fig. 8) were concentrated south of the western Alaska Peninsula to the central Aleutians. Seventy-eight percent of all catches showed either a southwestward, westward or northwestward direction of movement. These included near shore and offshore catches; a third of all catches were more than 200 miles south of the Aleutians. Two adjacent catches on 160° W. indicated opposite directions, one northward, the other southward and both somewhat contrasting the general westward movement.

In the Bering Sea during July and August, two catches indicated northward movement and both were located on 175° E.; a third catch near the eastern Aleutians on 170° W. showed westward movement.

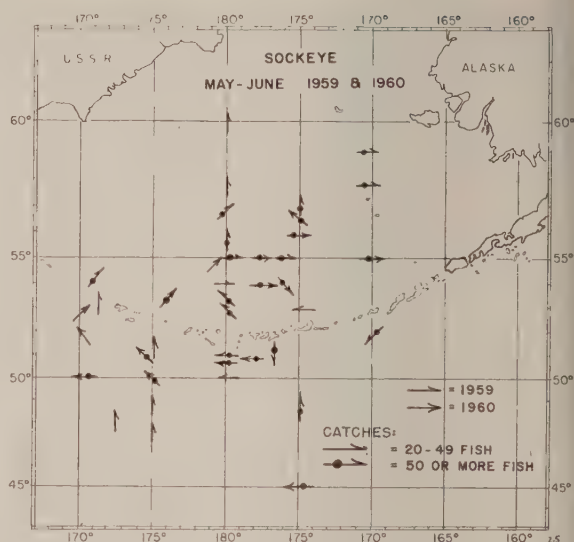


FIGURE 5. Dominant direction of movement of sockeye salmon indicated from gillnet catches during May and June, 1959 and 1960. Catches were composed mostly of mature fish.

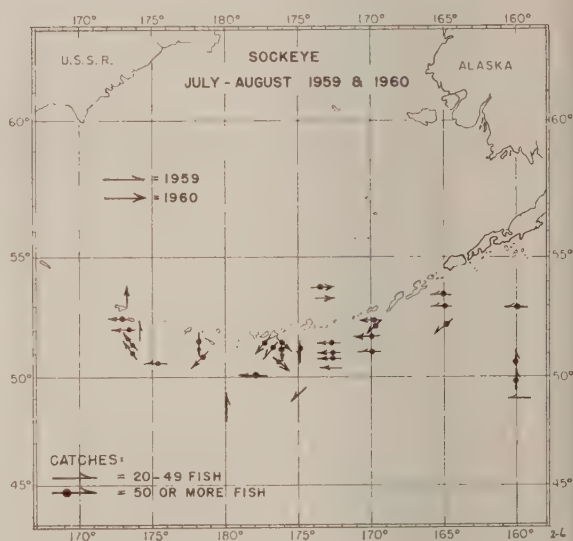


FIGURE 6. Dominant direction of movement of sockeye salmon indicated from gillnet catches during July and August, 1959 and 1960. Catches were composed mostly of immature fish.

Chum Salmon, 1960.

May-June. The direction of movement of chum salmon in the North Pacific during May and June (Fig. 9) was predominantly southwestward, westward, or northwestward as indicated by 13 of 15 catches ranging to 300 miles from the Aleutians. One catch (on 180°) contrasted the general westward movement,

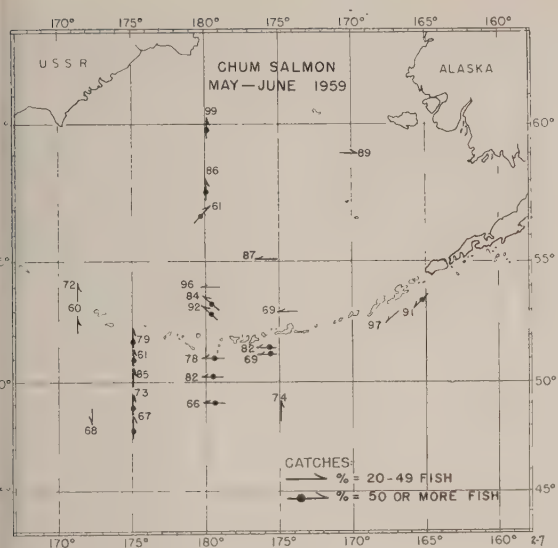


FIGURE 7. Dominant direction of movement of chum salmon indicated from gillnet catches of the *Pioneer* and *Tordenskjold* during May and June 1959. Numbers are percentage of catch. Catches were composed mostly of mature fish.

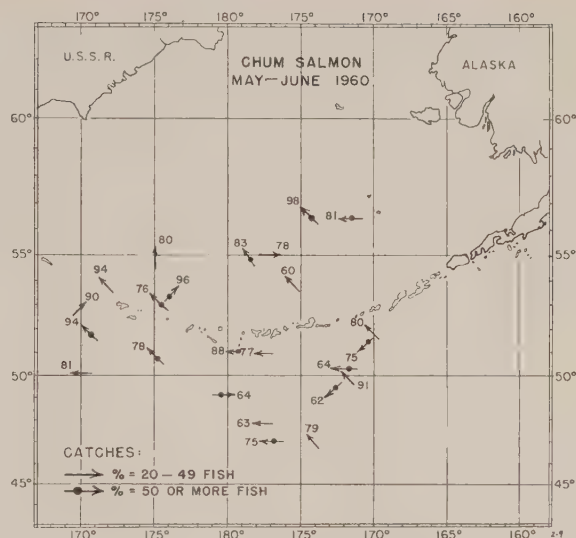


FIGURE 9. Dominant direction of movement of chum salmon indicated from gillnet catches of the *Paragon* and *Pioneer* during May and June 1960. Numbers are percentage of catch. Catches were composed mostly of mature fish.

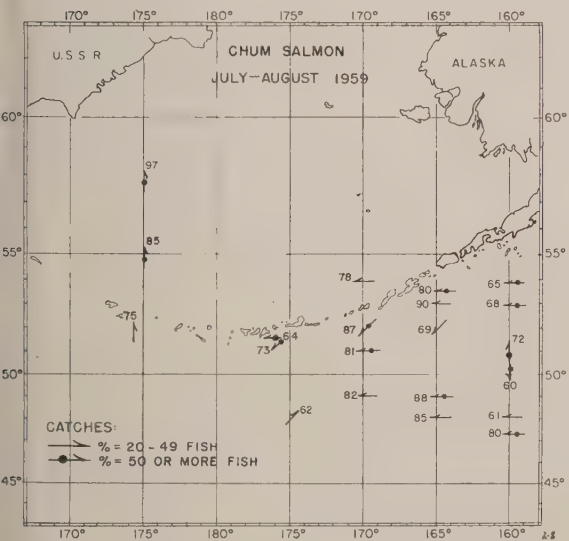


FIGURE 8. Dominant direction of movement of chum salmon indicated from gillnet catches of the *Pioneer* and *Tordenskjold* during July and August 1959. Numbers are percentage of catch. Catches were composed mostly of immature fish.

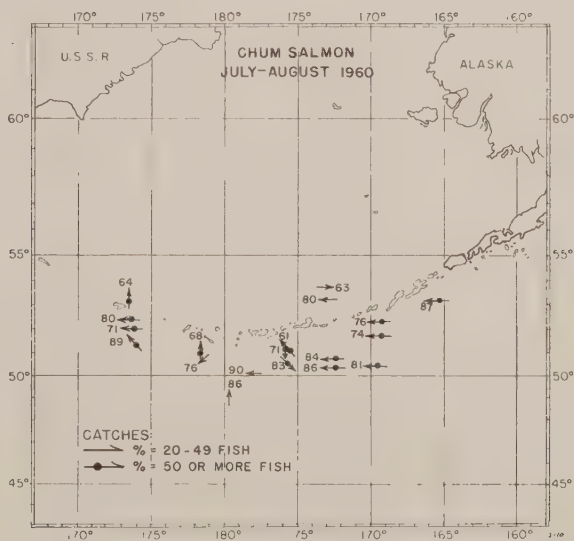


FIGURE 10. Dominant direction of movement of chum salmon indicated from gillnet catches of the *Paragon* and *Pioneer* during July and August 1960. Numbers are percentage of catch. Catches were composed mostly of immature fish.

indicating an eastward direction, and a catch near the western Aleutians showed a northeastward movement.

Six of the nine catches from the Bering Sea in May and June indicated westward or northwestward direc-

tion of movement. Single catches indicated northward, northeastward and eastward movement.

July-August. The majority of the catches (12 of 16) from the North Pacific during July and August (Fig. 10) indicated a southwestward, westward or north-

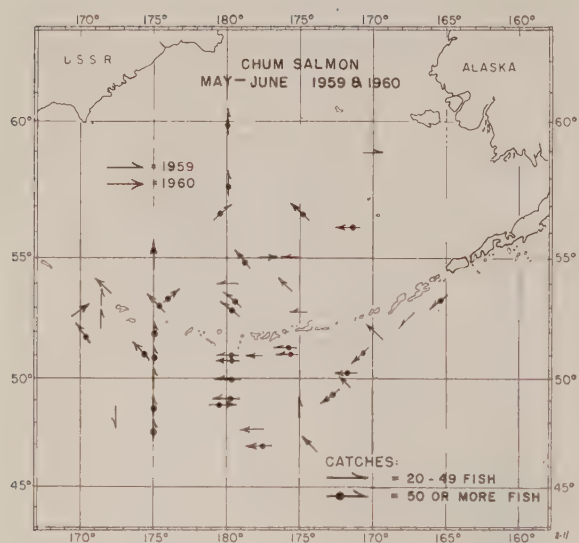


FIGURE 11. Dominant direction of movement of chum salmon indicated from gillnet catches during May and June, 1959 and 1960. Catches were composed mostly of mature fish.

westward direction of movement. Of three adjacent catches south of Attu Island, two indicated a westward movement and the third northwestward. Catches in the eastern Aleutians were consistent in showing a westward movement; however, those in the central Aleutians indicated a wide variation in direction of movement. This variation in movement was particularly evident south of Adak Island where four large catches in a relatively small area indicated four different directions of movement; hydrographic conditions may have influenced interpretation of these data, as mentioned.

Bering Sea catches during July and August consisted of one catch near the western Aleutians (173°E.) showing northward movement and two adjacent catches near the east-central Aleutians (173°W.) which indicated opposite directions of movement, one eastward and the other westward.

Chum Salmon, 1959 and 1960.

May-June. Catches of chum salmon during May and June (Fig. 11) in both 1959 and 1960 showed a general westward movement on the south side of the eastern Aleutians and both south and north of the central Aleutians to about 54° N. Northwestward and northward movement was evident in the western Aleutians. Movement indicated from the scattered catches in the north-central Bering Sea was generally northward but ranged from westward to eastward.

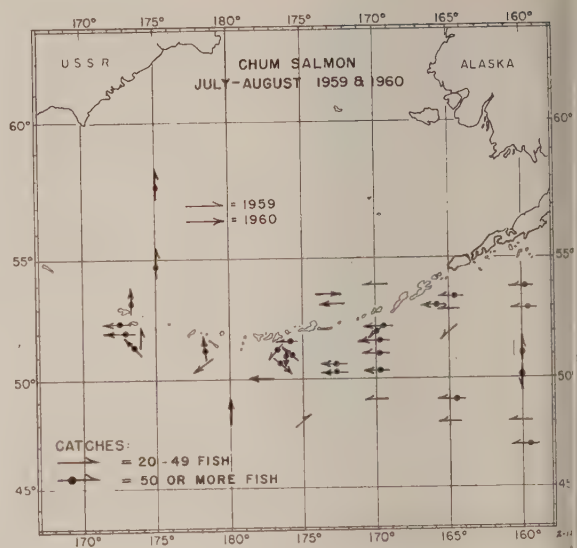


FIGURE 12. Dominant direction of movement of chum salmon indicated from gillnet catches during July and August, 1959 and 1960. Catches were composed mostly of immature fish.

July-August. A westward movement was indicated from July and August catches (Fig. 12) in both years south of the eastern Aleutians, but movement near the central Aleutians (175°W.-180°) in 1960 was variable. The fishing effort, farther westward in 1960, provided some evidence of westward and northward movement in the western Aleutians. Few catches in either year were made north of the Aleutian Chain.

Pink Salmon, 1959.

May-June. Pink salmon catches during May-June (Fig. 13) indicated a dominance (82 percent) of westward, northwestward and northward direction of movement in both the North Pacific Ocean and the Bering Sea. Most catches were from the Bering Sea between 175°W. and 180° longitude. Two of the three small catches in the Bering Sea were distinct in that they were the only catches indicating a southward direction of movement. Two catches nearest the Chain on the south side and all those on the north side through 55° N. indicated a westward or northwestward direction of movement. One catch north of the Pribilof Islands (170°W.) was unique being the only catch of pink salmon showing an eastward direction of movement.

July-August. A general westward movement of pink salmon (southwestward to northwestward) was indicated by six of seven catches concentrated around

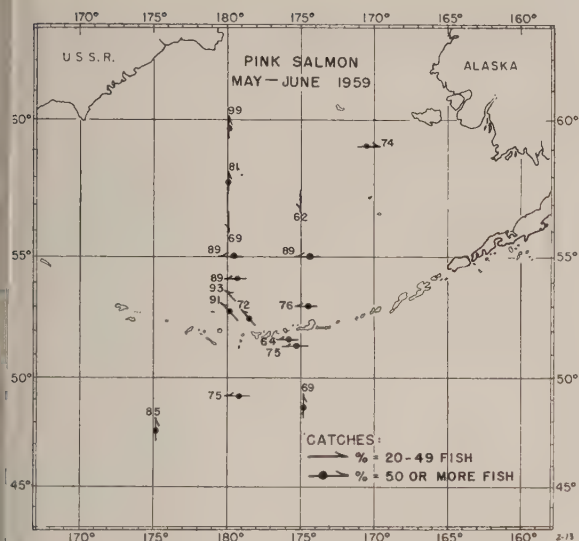


FIGURE 13. Dominant direction of movement of pink salmon indicated from gillnet catches of the *Pioneer* and *Tordenskjold* during May and June 1959. Numbers are percentage of catch. Catches were composed of mature fish.

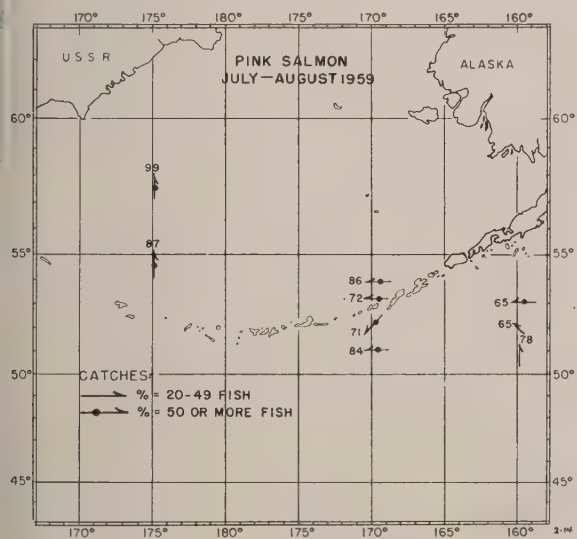


FIGURE 14. Dominant direction of movement of pink salmon indicated from gillnet catches of the *Pioneer* and *Tordenskjold* during July and August 1959. Numbers are percentage of catch. Catches were composed of mature fish.

the eastern Aleutians during July and August (Fig. 14). Two of these were in the Bering Sea and five in the North Pacific; all were on 160°W. or 170°W. Two catches north of the western Aleutians (175°E.) indicated northward movement.

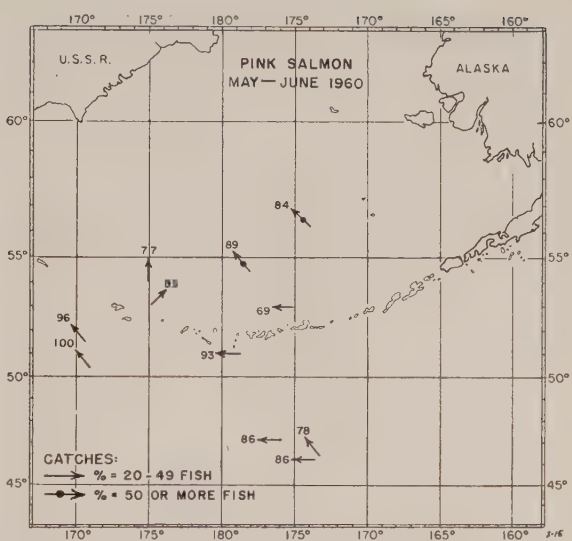


FIGURE 15. Dominant direction of movement of pink salmon indicated from gillnet catches of the *Paragon* and *Pioneer* during May and June 1960. Numbers are percentage of catch. Catches were composed of mature fish.

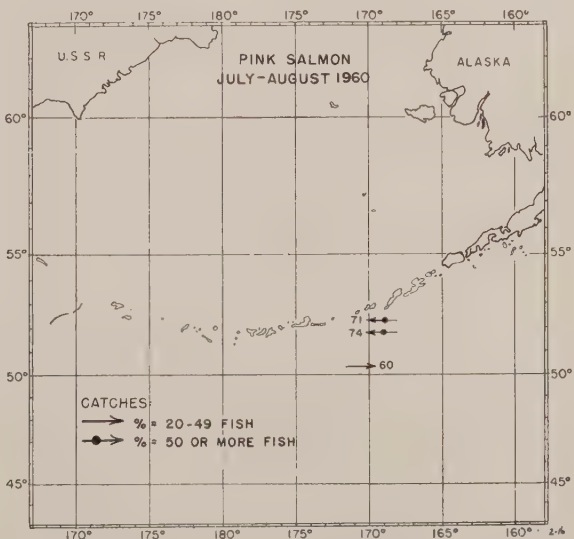


FIGURE 16. Dominant direction of movement of pink salmon indicated from gillnet catches of the *Paragon* and *Pioneer* during July and August 1960. Numbers are percentage of catch. Catches were composed of mature fish.

Pink Salmon, 1960.

May-June. Pink salmon catches in May and June (Fig. 15), although small, few and widespread, showed a general westward movement as much as

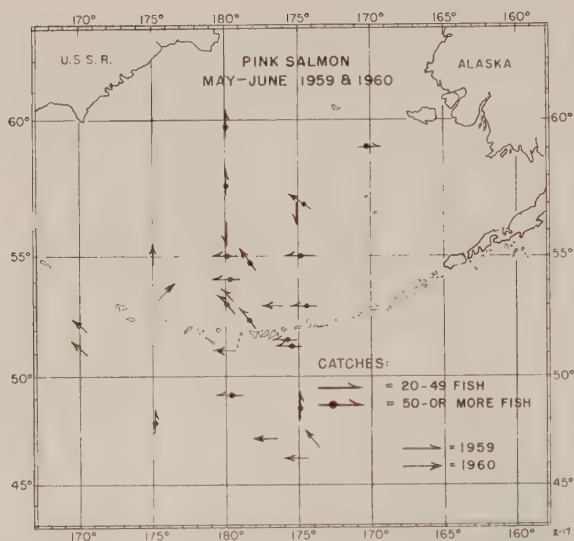


FIGURE 17. Dominant direction of movement of pink salmon indicated from gillnet catches during May and June, 1959 and 1960. Catches were composed of mature fish.

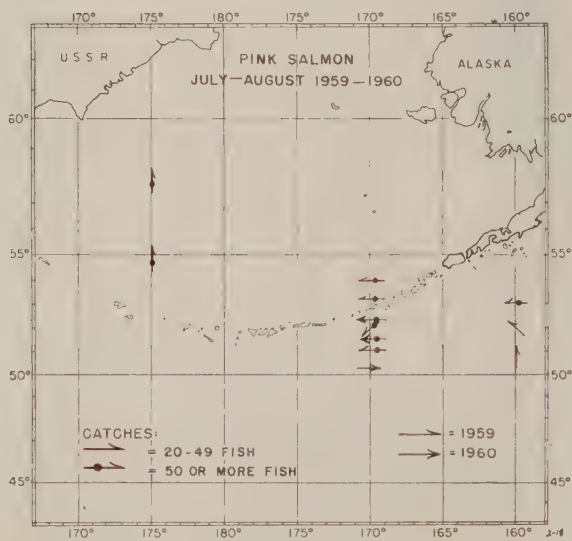


FIGURE 18. Dominant direction of movement of pink salmon indicated from gillnet catches during July and August, 1959 and 1960. Catches were composed of mature fish.

300 miles from the Aleutians in the Bering Sea and the North Pacific Ocean. Nine of 11 catches indicated either a westward or northwestward direction of movement; six of 11 were from the North Pacific.

July-August. The three catches of pink salmon in July and August (Fig. 16) were located in a relatively small area immediately south of the Aleutians on

170° W. Two catches indicated a westward direction of movement but the third and farthest offshore catch indicated eastward movement.

Pink Salmon, 1959 and 1960.

May-June. Catches of pink salmon in May and June 1959 were large, numerous and located mostly in the central Bering Sea, whereas those in 1960 were small, few and about equally divided between the North Pacific Ocean and the Bering Sea (Fig. 17). The movement indicated by the majority (68 percent) in both years was westward or northwestward, with some indication (18 percent) of northward movement.

July-August. July-August catches (Fig. 18) were few in each year and were located mainly in the eastern Aleutians with about two-thirds indicating a general westward movement.

DISCUSSION

COMPARISON BETWEEN SPECIES

Movement direction of sockeye, chum and pink salmon during the 1959 and 1960 sampling seasons was similar, particularly in the summer sampling period in the North Pacific. Some variation between species was nevertheless apparent, most noticeably north of the central Aleutians when comparing sockeye with pink salmon and to a somewhat lesser extent when comparing sockeye with chum salmon.

May-June.

The direction of movement of each species in the North Pacific was predominantly westward south of the eastern and central Aleutians and northwestward to northward south of the western Aleutians during May and June (Figs. 5, 11 and 17). Few pink salmon were caught in the western Aleutians.

Catches of each species in the Bering Sea near the Aleutian Chain and north from 56°N. indicated generally similar movement; however, in the area roughly bounded by latitudes 54°N. to 55°N. and longitudes 175°W. to 179°E., the predominant direction indicated by sockeye salmon catches was eastward as opposed to westward and northwestward by chum and pink. The majority of fish in catches of the May-June period was mature; to spawn, these mature fish travel to streams of the Asian or North American continent. Thus, the difference in direction of movement between sockeye and both chum and pink salmon, particularly pink, implies their ultimate destinations were eastward and westward respectively from this portion of the Aleutian "feeding grounds".

54° N–55° N.). (An exception would be fish destined for Aleutian Island streams southward from the area referred to.)

July–August.

In July and August sockeye and chum catches (Figs. 6 and 12) in the North Pacific showed a marked westward direction of movement. Catches of both sockeye and chum showed an area of variable movement south of the central Aleutians. The few catches of pink salmon (Fig. 18) indicated a direction of movement generally similar to sockeye and chum catches at the same locations although the comparison essentially was that of mature pink with immature sockeye and chum salmon.

Catches in the Bering Sea during July and August were few. Some contrast was noted near the Aleutians between 170° W. and 175° W. where an eastward movement was shown by sockeye salmon catches, whereas chum and pink salmon catches showed predominantly westward movement.

COMPARISON BETWEEN GILLNET AND PURSE SEINE

A rough comparison of direction of movement indicated by gillnet catches with that indicated by purse seine catches from 1956–1958 (Hartt, 1962) shows a definite similarity in most Aleutian areas; similarity is apparent for catches of a comparable time and area especially in the North Pacific. Generally the gillnets were fished offshore and purse seines near shore. Maturity composition of the catches from both types of gear was similar.

In the North Pacific, sockeye, chum and odd-year pink salmon catches from both types of gear strongly indicated that the westward direction of movement was predominant. (In the Aleutian waters large numbers of pink salmon have been caught only in odd-numbered years, thus for pink salmon it is 1957 purse seine catches and 1959 gillnet catches which are compared.) This westward movement appears to be generally consistent in both the spring and summer periods in near shore and offshore waters and most evident in the area between 165° W. and 175° W. Purse seine catches indicated a continued westward movement beyond 180° at least to 170° E., particularly for chum and pink, with also some indication of northward movement though the major Aleutian passes. On the other hand, gillnet catches west of 180° to 171° E. showed northward movement as dominant in May and June and westward movement as dominant in July and August for sockeye and chum salmon; few pink salmon were caught in this area.

In the Bering Sea, the direction of movement indicated by purse seine and gillnet catches was clearly westward for pink salmon north of the central Aleutians to 55° N. during May and June, the only period for which data are comparable; with the exception of eastward movement shown for sockeye salmon in the Pribilof Islands area, catches in the Bering Sea of both sockeye and chum salmon were not comparable.

In the North Pacific, the similarity in movement indicated by gillnet and purse seine catches suggests that from May to August between 165° W. and 175° W. and from 48° N. to the Aleutians this was an area of definite westward migration for mature sockeye, chum and pink salmon and immature sockeye and chum salmon; during May and June the westward migration extends to 180° longitude.

In the Bering Sea, similar movement shown by catches from these two types of gear is evident for pink salmon during May and June from the Aleutians north to 55° N.; here, too, a definite westward migration is suggested. Similarity in movement direction of sockeye salmon shown by catches near the Pribilof Islands provides evidence of an eastward migration in that area during May and June.

CONCLUSIONS

1. Gillnet catches of sockeye salmon in May and June indicated predominantly mature fish moving westward along the central Aleutians, northward through the western Aleutians and eastward in the Bering Sea between 54° N. and 55° N. and 180° and 175° W. as well as near the Pribilof Islands (160° W.). Dominant movement in the central Bering Sea was northward. July and August catches, mostly of immatures, showed a general westward movement in the North Pacific from 160° W. to 175° W., variable movement between 175° W. and 175° E. and westward to 173° E., the westernmost fishing location.

2. Chum salmon catches in May and June showed a dominance of mature fish moving westward in both the North Pacific and the Bering Sea except northward through the western Aleutians and the west-central Bering Sea. North Pacific catches in July and August were largely immatures moving westward in all areas except the central Aleutians, where variable movement was evident.

3. General westward movement from May through August was shown by all pink salmon catches except those from the central Bering Sea.

4. Similar movement was shown by all species in the North Pacific.

5. A comparison of movement in the Aleutian area indicated by gillnet catches in 1959 and 1960 with that indicated by purse seine catches from 1956–1958 shows general agreement in the North Pacific Ocean, and for sockeye salmon in the Pribilof Islands area of the eastern Bering Sea, as well as for pink salmon throughout the comparable Bering Sea area. Similarity in movement shown by these two types of gear was most evident south of the Aleutians between 165° W. and 180° longitude in May and June and between 165° W. and 175° W. during July and August.

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by James H. Johnson

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The Pacific Coast Tuna Fleet

by James H. Johnson

Only one of our fleets seems to be holding its own as U. S. fishermen try to fathom the government's apparent indifference to their plight. Many, including the author, are asking why our international trade policies seem to discriminate against domestic fishermen who might otherwise give this country pre-eminence in the fisheries of the world and, at the same time, reap a rich harvest of oceanographic data for our Navy.

For the past several years, numerous articles have implied that the United States possesses a second rate fishing fleet in the throes of serious economic difficulty. Further, it has been suggested that the U. S. fleet, instead of meeting the challenge provided by the fleets of Russia and Japan, is succumbing to this pressure. Some of these articles create an unfavorable image of the domestic fisherman; they say that he resists change and has fallen behind fishermen of other nations in technological developments required to increase his efficiency. Undeniably, the U. S. fishing fleet has declined alarmingly over the past decade, but probably it is only because of the resourcefulness and resiliency of U. S. fishermen that various fisheries have survived at all. Certainly U. S. policy as to international trade has been unfavorable to domestic fishermen and has played a significant role in the decline of the fleet. This is in contrast to the policies of Japan and the Soviet Union, for example, which have created a healthful climate for expansion of their fisheries.

One of our fishing fleets that thus far has been able to rise to the challenge of foreign competition is the West Coast tuna fleet. In spite of being brought to its knees time and again over the past decade because of the impact of foreign imports and for other reasons which will be discussed later, this fleet continues its fight for survival with increased vigor—and is the most important high seas fleet in the United States today. In 1962, ranging from Vancouver Island to northern Chile, it produced 150,000 tons of tuna valued at 40 million dollars to the domestic fisherman. No other U. S. fishing fleet has ranged as far in harvesting an ocean resource.

A prerequisite to understanding, the operations of our West Coast tuna fleet is an acquaintance with methods of harvesting

tuna and with tuna distribution in the Pacific Ocean. Methods of fishing include trolling (jig fishing), live bait fishing, purse seining, and long line fishing. Trolling for tuna is the act of towing barbless hooks on long, single lines attached to a pair of outriggers extending from the sides of a vessel. Hooks are baited with artificial lures (jigs). Live bait fishing involves discovering a school of tuna and then attracting it to the side of a vessel by chumming with live bait, from whence this method derives its name. Once alongside, fish are captured with short bamboo poles and line baited with feathered lures or live bait. When catching fish up to about 25 pounds in weight, each man fishes individually with his pole and line. With fish above that weight, the fishing crew splits into teams of two, three, or four men. Each member of a team still retains his pole, but the line from each pole attaches to a common leader through a ring and swivel arrangement.

Purse seining is the use of an encircling type of net designed to catch species of tuna that run in schools near the surface. A typical net is about 425 fathoms long and has a depth of 40 fathoms. Capture is affected by surrounding the school, pursing or closing the bottom of the net and concentrating the catch in a small area of the net so that the catch can be readily brailled aboard the vessel with huge dip nets. Catches of over 100 tons in one set are not uncommon, but the average catch per set is about ten tons.

Long line fishing for tuna involves the setting of an extraordinarily long main fishing line from which branch lines with baited hooks are suspended at intervals. This is the dominant fishing method used by the Japanese in the Pacific for harvest of tuna. Fish taken by this method dwell well below the surface, usually residing above the thermo-

cline about 100 to 400 feet down. Because of the extensive labor involved in long line fishing, U. S. fishermen have not found it profitable to fish by this method.

For the sake of convenience in discussing distribution, the two main species which make up the catches of the U. S. tuna fleet can be classed into the temperate species, which includes the albacore and bluefin, and the tropical species, composed of yellowfin and skipjack.

Albacore of the Pacific Ocean are believed to be composed of North Pacific and South

Pacific populations. Tagging experiments have shown conclusively that the northern hemisphere population of this tuna make transpacific migrations. In winter, the center of abundance is in the central North Pacific and this is the area exploited by Japanese long line fishermen. In spring, feeding migrations occur to coastal waters of Japan—where live bait fishing by the Japanese is carried out from April through July—and to coastal waters of North America—where trolling and live bait fishing by U. S. fishermen take place from June through October. Purse seining has been tried from time to time but, as yet, has met with little success. The South Pacific albacore is exploited mainly by Japanese long liners.

The riddle of the Pacific bluefin tuna, which appears for three months each year off Baja California, was solved last year when the first transpacific migration of bluefin was recorded on 23 April 1963. A small Japanese longliner recovered a bluefin south of Japan that had been tagged in 1958 off Guadalupe Island, Mexico. Similarly, the Atlantic bluefin has been found to make transatlantic migrations.

Yellowfin and skipjack are distributed in tropical waters from coastal America across the entire Pacific. The fishery in the eastern Pacific by U. S. fishermen is by the live bait method and by purse seining. One reason that purse seining appears to be successful in the eastern Pacific is that this is a region of a relatively shallow thermocline (30 to 200 feet). The tropical tunas residing in the shallow upper mixed layer avoid the sharp temperature discontinuity of the thermocline and thus become vulnerable to the seines of the fishermen. As the thermocline deepens to the westward in the Pacific, purse seines appear to be less effective.

Failure of the run of sardines off southern California in 1903 is reputedly the cause for development of the tuna fishery. The following quarter century saw a gradual increase in the size of the fleet, the size of vessels, and an expansion of the fishing grounds. By 1930, the day of the large bait boat, or tuna clipper, as it is commonly called, had arrived. Vessels were fishing as far south as the equator and, with the advent of brine refrigeration in the late 1930s, the working time and range of the fleet were further increased. Vessels now could



remain at sea for months without fear of spoilage of the catch. The outbreak of World War II found an active building program of large tuna vessels, and many new vessels were entering the fleet. Forthwith, the U. S. Navy took these vessels and sent them with crews intact to the South Pacific. It was following the design of one of these vessels, the *Madeira* (now the *Judy S*, fishing out of Peru), that the Navy constructed about 50 YPs. When hostilities ceased in 1945, the Navy returned the surviving vessels to their owners and made others available for purchase. Vessels fishing tuna today which formerly were constructed as YPs by the U. S. Navy are:

Alphecca (YP-639)
American Enterprise (YP-630)
Cape Falcon (YP-645)
Corsair (YP-634)
High Seas (YP-621)
Intrepid (YP-640)
Mariner (YP-619)
Ranger (YP-638)
Ronnie S. (YP-627)
San Joaquin (YP-641)
Santa Rosa (YP-636)
St. Mathews (YP-631)

For about five years following World War II, the economic climate for expansion of the U. S. tuna fleet was healthful. Imports were not yet available. Profits were good and were directed toward building new vessels. The big producers were bait boats out of San Diego. The bait boat fleet grew from 75 vessels with a carrying capacity of 8,445 tons, in 1945, to 225 vessels having a carrying capacity of about 50,000 tons, in 1951. At this time, the San Diego bait boat fleet produced about 75 per cent of the U. S. tuna catch; the San Pedro purse seine fleet produced about 15 per cent; and the albacore fleet, about 10 per cent.

Peak production of tuna was in 1950 when the West Coast tuna fleet took approximately 200,000 tons, valued at 60 million dollars, in the eastern Pacific. In that year, however, the first sizable amounts of tuna from Japan were imported and, since that time, the fleet has had to weather one economic crisis after another. Subsequently, except for a short period in 1954 and 1955 and again in 1961 and 1962, prices have declined steadily. Be-

cause of ever-increasing world demand for tuna, however, this trend may be arrested. The effect of imports on the fleet was devastating, and when imports of tuna from the newly established Japanese Atlantic fishery hit heavily in 1959, it appeared for a time that tuna fishing by the domestic fleet might disappear entirely. Table I shows clearly the decline of the tropical fleet from over 300 vessels in 1951 to 139 vessels in 1962. The albacore fleet, although exact figures are not available, certainly numbers under a thousand today, less than one half of its size in 1950.

Table I

U. S.-based, long-range vessels engaged in the eastern tropical Pacific tuna fishery during the years from 1950 to 1963. This includes vessels operating from Puerto Rico but not those operating from other foreign ports.

Year	Bait boats	Purse seiners	Total
1950	204	67	271
1951	225	78	303
1952	202	64	266
1953	190	64	254
1954	182	69	251
1955	172	63	235
1956	175	64	239
1957	170	50	220
1958	158	44	202
1959	141	53	194
1960	69	82	151
1961	44	114	158
1962	36	103	139
1963	30	111	141

In 1956, however, the first seeds of technological advances which were to revolutionize the tropical fishery occurred with the development of the nylon net and the power block for improved hauling of seines. Lack of capital and natural reluctance on the part of fishermen to change their method of fishing delayed rapid conversion of bait boats to purse seiners. It soon became evident, however, that large purse seiners could operate much more efficiently than bait boats. Accordingly, even though cost of converting to purse seiners ranged from \$50,000 to \$150,000 and cost of the all-nylon purse seine was approximately \$50,000, conversions increased

gradually and then, in 1959 and 1960, jumped to an unforeseeable rate. Few events in the history of a major fishery have so completely revolutionized a fishing fleet. Today in San Diego, the large clipper or bait boat of the early 1950s is a rare sight.

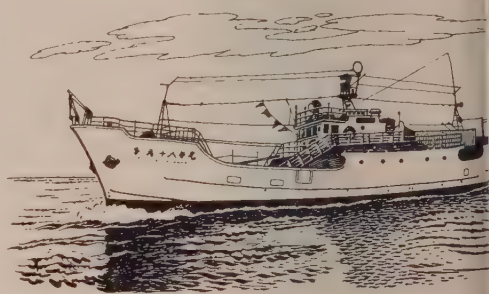
Not only did conversions from the clipper fleet occur at a rapidly expanding rate, but several military types were converted to seiners. The *Clipperton*, first of the recent conversions from the military type, was formerly the Army freighter, FS-228; she has a carrying capacity of 550 tons. The *Lexington* and *Reefer Queen*, also recently converted from FSs, each have a capacity of 800 tons. Another type that has adapted well to conversion is the minelayer. The first of this type, the former U. S. Navy minelayer MMA-13, entered the fleet in 1961 as the *Nautilus*, carrying capacity 800 tons. The *Pilgrim* and *Puritan* commenced fishing early in 1963, having been converted at Jacksonville, Florida, from hulls similar to that of the *Nautilus*. The world's largest tuna seiner, the *Day Island*, with a carrying capacity of 1,000 tons, departed San Diego in March 1963 on her maiden voyage. She is the former U. S. Army Coast Artillery Corps Col. C. W. Bundy. Her sister ship, the *San Juan*, joined her a few weeks later, having been converted from the Col. George Ricker.

In 1961, the *Royal Pacific*, the first seiner built from keel up for many years, was launched. The *Hornet*, also built from the keel up, entered the fleet late in 1962; and the *Caribbean*, similar to the *Hornet*, joined the fleet in mid-1963. The *Royal Pacific* is 142 feet overall; she has a 33.5-foot beam, and a 15-foot 9-inch moulded depth. She is constructed of wood, propelled by a Fairbanks-Morse 10-cylinder diesel that produces 1,600 horsepower and drives the vessel at about 12 knots cruising speed. She carries late-model, high-seas-frequency radiotelephone equipment, a thermograph to record sea temperatures continuously, and a bathythermograph installation for measuring the vertical temperature distribution, part of a co-operative program with the U. S. Navy and the Bureau of Commercial Fisheries. Soundings are provided by two Fathometers; one has a 1,000-fathom range for offshore fishing and the other has a 160-foot range for coastal work. The nylon

net carried on board is 480 fathoms long and 50 fathoms deep. The *Royal Pacific* has a capacity of 450 tons of tuna. The *Hornet* is an all-steel-hull vessel that can carry 700 tons of tuna. The estimate of the cost of construction of this type of vessel is a little more than one million dollars.

The tropical fleet, then, has drawn new breath by conversions and new construction but the albacore fleet remains in a poor competitive position with imports. Few, if any, new boats are entering the fleet, although many of those which are now fishing are in extreme need of replacement. Capital, however, for new construction in this small-boat fleet is not available.

As was mentioned earlier, a major problem facing the tuna fishermen is that of competition by fishermen of foreign countries. Over the past 40 years, domestic consumption of canned tuna has nearly doubled every ten years. In 1949, the supply for canning, from all sources, was 368 million pounds, and, in 1958, it reached 669 million pounds. The domestic fishermen, however, continued to produce about the same amount over that decade. Yet, imports jumped from a mere 19 million pounds in 1949 to 337 million pounds in 1958. Countries making major import contributions are Japan and Peru; Japan



supplied over 80 per cent of the imports during eight of the years from 1949 through 1958.

The first year U. S. fishermen were seriously affected by imports was 1951. Since that time, in roughly every odd-numbered year, the domestic fleet has found itself in severe and, in some instances, near catastrophic economic conditions. Because of the development of the nylon net and power block however, which increased the efficiency of the

ropical fleet, it is literally scrambling off the floor and again finds itself competitive. Albacore fishing, on the other hand, continues to be a marginal operation. The price paid to the albacore fisherman for his product has dropped from a high of \$740 a ton in 1948 to \$275 a ton in 1963.

Table II

Imports of tuna into the United States from Japan, Peru, and other countries from 1949 to 58 inclusive in millions of pounds.

Year	Japan	Peru	Other Countries	Total
1949	12	6	1	19
1950	95	18	4	117
1951	63	15	7	85
1952	95	15	6	116
1953	147	15	3	165
1954	165	22	5	192
1955	191	25	12	228
1956	185	18	13	216
1957	213	27	20	260
1958	285	30	22	337

Japan is the world's leading producer of tuna. During the early part of this century, the Japanese fishery for tuna was adjacent to the home islands. As the demand for tuna increased, it soon became abundantly clear that further increases in production would require exploitation of new grounds. In the 1930s, extensive explorations were made in the entire western Pacific and in the Indian Ocean. This exploration and expansion of the fisheries was arrested in the late 1930s and early 1940s, however, because of military operations. Following World War II, Japanese fisheries were limited by Allied military control, but with the end of occupation in 1952, fishing vessels rapidly expanded operations into the central, western, and south Pacific and the Indian Ocean. The prewar research and exploration paid handsome dividends to this postwar expansion. In 1956, further expansion carried the Japanese fleet into the Atlantic Ocean, and recent years have found considerable Japanese fishing activity in the eastern tropical Pacific. So successful have they been in these operations that the Japanese now harvest well over one-half of the world's total production. The

success of tuna fishing by the Japanese is further mirrored in the increase in gross tonnage of their tuna fleet from 78,517 gross tons in 1947 to 197,760 gross tons in 1956. More recent figures show that, in 1961, gross tonnage was approaching 250,000 tons. This remarkable growth has been accomplished largely through efforts by Japan to provide a favorable economic climate for expansion of the fisheries and the fishing fleet, and the growth apparently will continue at a high rate. *Pacific Fisherman Yearbook 1963* reports that the Japanese tuna fishing fleet will increase by 20,000 gross tons in 1963 and 1964 with the addition of several new long-liners.

Recent statistics published by the Food and Agriculture Organization of the United Nations further attest to the importance of Japan in the world fishery. FAO experts reported that Japan was the world's leading fishing nation in 1961 with a production of 6.7 million metric tons. Peru was next with a catch of 5.2 million tons, followed by mainland China, U.S.S.R., and the United States. Just considering tuna and tuna-like fishes (bonito and mackerel) Japan still was reported as being the world's leading producer, having landed one million metric tons, followed by the United States and Peru, both with under 0.2 million tons. Although Japan's fishermen are among the world's best, they are no more efficient than our own. In fact, it is likely that, in production per man per year, Japan lags behind the United States. Her tremendous success stems from nationwide emphasis on her fisheries and much lower labor costs than those found in the United States.

The Soviet Union has not yet figured prominently in production of tuna, but she has given every indication recently that she plans to enter actively into this fishery. Considering her outstanding successes in other of the world's fisheries, one may rest assured that in a short time she will become a powerful force in the high seas tuna fishery. Her large factory ships, permitting catches to be processed at sea and providing advanced logistic facilities for her fishing fleets, will permit operations independent of home bases for extended periods. These features appear to make the Soviet Union's operations particularly suitable for the harvesting of tuna.

Our foreign trade in fishery products may work to the disadvantage of the U. S. fishermen in another way. Because of imports, the domestic fisherman has at times been unable to market all he can catch. In some cases, prices for his catch have also declined because of the imports. While he is adversely affected by an increase in imports and relatively low duties, his position is further complicated by a law passed in 1792 which requires that he must build his fishing vessel in the United States. This costs him up to twice as much for a vessel as it would to have it built in a foreign country. In 1960, a Fishing Vessel Construction Differential Subsidy was passed whereby certain fishermen could have a good percentage of the cost of a vessel subsidized. The provisions of this law, however, are applicable only to those fisheries which have been determined by investigations to have been injured by imports. This raises difficulties, for in today's fiercely competitive world fishing trade, wherein armadas of foreign vessels operate at our doorstep, it would be a Herculean task to rebuild a broken fleet. If aid is to be effective, it must occur before our fishing fleets are demoralized and near disintegration. Happily more liberal subsidization for the building of fishing vessels

is now under consideration by Congress.

Another problem plaguing the tropical fisherman, generally unknown to the public, is the harassment that he has received over the past decade from countries bordering the tropical eastern Pacific Ocean. This stems chiefly from the inability of nations of the world to reach agreement on the "Law of the Sea." And it is, indeed, frustrating to the U. S. tuna fisherman, because, of course, as an individual, he has no voice in this matter.

Two elements are involved—breadth of the territorial sea and jurisdiction by coastal countries over fisheries lying in adjacent seas. Within the past five years, nations of the world have met twice to reach agreement on the fixing of territorial limits and jurisdiction of coastal fisheries, and twice they have failed. It does not appear likely that a third conference will be held in the foreseeable future. Conflicting interests—fishing, military, political, economic, social, domestic, and international—have created problems of incredible complexity. Unfortunately, the living resources of the sea are not bound by lines of jurisdiction set unilaterally by many countries; and the hapless fisherman, in pursuit of these resources, often becomes ensnared in the web of international disagreements.



Historically, the United States and other powerful maritime nations have observed the three-mile territorial limit as a rule of international law. Both in peace and war, maritime nations work to keep the sea lanes open. However, many nations have claimed a 12-mile limit. This works to their advantage in the interdiction of sea traffic.

The emergence of many new nations in the past two decades, with attendant fishery interests, and the newly developed fisheries of several of the older nations are now causing, and will continue to cause, serious, international problems in that some of these countries are claiming six, 12, or even hundreds of miles of territorial sea.

The 1958 Geneva Conference on the Law of the Sea, attended by representatives of 85 nations, although reaching important agreements on freedom of the high seas and fishing and conservation matters, failed in its attempt to fix territorial limits and fishery jurisdiction. At the latest conference, held in Geneva in April 1960, the United States, favoring a three-mile limit but fearing it had no chance of passage, introduced jointly with Canada a proposal for a six-mile limit plus six miles for fishery control. This proposal, requiring two-thirds majority of the 88 nations represented, failed passage by one vote. Following defeat of the U. S.-Canadian proposal, the U. S. representatives asserted that their country would adhere to the customary three-mile limit as it had in the past.

According to records provided by the American Tunaboat Association of San Diego, California, harassment in some form or another to our fishing fleet occurred no less than 20 times in 1961 and 1962. This harassment occurred even though our vessels were outside the three-mile territorial limit, and, in some instances, were 30 miles offshore. These highhanded acts included checking of documents, imprisonment of masters and crew, imposition of heavy fines, and firing upon our vessels by naval craft of foreign countries. It must be ironic for the U. S. fisherman to realize that he is being chased from the high seas by naval forces of countries to which we have supplied combatant ships under the Military Assistance Program.

Consider the case of the *White Star* that was apprehended in August 1962 by the Ecua-

dorian government and held for five weeks before being released. Although no fines were imposed, the fishing time alone, forever lost, could conceivably have cost the vessel up to \$50,000. (Based on records of catch per day for 1961, the demurrage cost for tuna vessels runs approximately \$500 to \$1,000 or more per day.) Another incident involved seizure by Peruvian officials of the vessels *Western Ace* and *Chicken of the Sea*, both of which were reported to have been over ten miles offshore at time of seizure in 1963. The vessels were released a few days after seizure but paid fines amounting to \$15,000. Subsequently, these vessels were reimbursed in the amount of the fines under the Fisherman's Protective Act, which provides that vessels unlawfully seized will be repaid fines imposed. In most cases, however, the lost fishing time is more costly than fines and as yet there has been no way to collect for lost time. The reasons why the U. S. government has not done more to correct this situation are not well understood by fishermen who admit to naïveté in the field of international politics, but who know that under domestic law the United States is obligated to protect its vessels and owners against unlawful seizure by foreign governments. It is obvious that our government has given first consideration to other national interests overriding those of the fishermen. Latest indications are, however, that the U. S. government, in action long overdue, is taking forthright steps to stop these illegal seizures of its ships.

The concept of conservation of the living resources of the oceans states that harvesting of a commercially valuable resource should be at a rate that will produce the maximum sustainable yield. Harvesting at a greater rate is an extravagance that will lead to decimation of the resource and its ultimate destruction for commercial purposes; nor can harvesting of less than the maximum yield be countenanced in this day when many nations of the world are in desperate need of protein.

Findings of the Inter-American Tropical Tuna Commission, located at San Diego, California, have indicated that the yellowfin stock of the eastern Pacific responds rapidly to fishing intensity and that the annual maximum sustainable yield is about 97,000 tons. The increased efficiency of the fleet, realized

from conversion of bait boats to purse seiners, did, indeed, cause the catch to rise above this level in 1960. In 1961, the Commission recommended to its member governments that the yellowfin fishery be regulated. Legislation for regulation passed the U. S. Congress in 1962, but the effects of over-fishing the stock in 1960 and 1961 are already apparent in a lower harvest. This means that, for a period of time,



the annual harvest will have to be lowered to permit the maximum sustained yield to rise again to 97,000 tons. The effect of the decline in the abundance of yellowfin in the eastern Pacific will be an increase in fishing pressure on other species and in exploration of the world's oceans to discover other harvestable tuna stocks.

While changes in absolute abundance of tuna are obviously a problem to fishermen, so are movements of the tuna as they range the oceans in feeding and spawning migrations. Over the years, fishermen have accumulated a vast amount of empirical knowledge to enable them to determine where to go seasonally to find fish. In many years and seasons, however, to the dismay of the fisherman, his "rule of thumb" breaks down and he is left literally with an empty bag. Heretofore, fishery oceanographers in post-mortems of these fluctuations in availability have been able to explain in part, on the basis of a changing ocean environment, why the changes in distribution of tuna occurred. However inter-

esting this may be to the fisherman, it is no much solace to him to know why he may have failed last year. The trend now is toward increased emphasis by fishery oceanographers in understanding the ocean, ultimately to lead to prediction of these changes in spatial and temporal distribution of tuna. Model prediction programs are meeting with limited success. The complexity of these programs is reflected in the recent findings of scientists that in some years the success of tuna fishing in the southern hemisphere off Ecuador and Peru is related to the position of the North Pacific High Pressure System many thousands of miles away.

The tuna fisherman, too, is beginning to comprehend the importance of understanding ocean processes and prediction thereof to increase his efficiency. The collection and use of certain oceanographic data by fishermen has special significance to the U. S. Navy. For example, it is becoming increasingly apparent to the purse seine fisherman that a direct relationship exists between depth of thermocline and his fishing success. Over a shallow thermocline, fishing appears to be more successful than it is over a deep one. The tentative explanation for this is that, when the thermocline is shallow, the purse seine falls below it. Tuna, avoiding the sharp drop in temperature of the thermocline, remain in the upper mixed layer vulnerable to the seine. If, however, the seine does not reach thermocline depth, the tuna may escape under the net before it is pursed.

For successful prosecution of an effective antisubmarine warfare effort, no environmental feature is as important as knowledge of depth of the thermocline, its seasonal and nonseasonal variations, and predictions made thereof. The potential value of having a fleet of fishermen taking bathythermograms for fishing operations and then reporting thermocline depths to shore-side facilities for analysis and use in the U. S. Navy ASW effort appears to be indisputable.

It is inconceivable that the Navy and the fishing fleet, both depending upon the sea for their very life and both requiring precisely the same information, albeit for different purposes, can long remain apart. That fishermen are capable of collecting such data has been demonstrated to a limited extent by



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masters of several purse seiners which are now operating out of San Diego.

Another feature important to the Navy's ASW operations is knowledge of topographic features of the ocean floor. Tuna fishermen, also, have more than a casual interest in bathymetry, for the tuna appear to aggregate around seamounts and other protuberances rising above the ocean floor. It is obvious that the fishing fleet could make a major contribution to the national oceanographic effort here, too, by routinely charting the ocean depths as vessels roam the Atlantic and Pacific in search of tuna.

The true potential, however, of utilization of the fleet lies virtually untapped. By our own admission, we decry our lack of knowledge of the oceans; yet, at our very doorstep are available the many floating platforms capable of collecting some of the oceanographic data so vitally needed.

The fact that fishing vessels often operate in areas remote from normal shipping lanes should further suggest their value in an ocean-wide antisubmarine warfare program. Furthermore, fishermen live by what they see at sea and their visual perception is almost unbelievably acute to a landsman. As they now search the eastern Pacific in great detail, there is little that they do not collectively see and, as the area of fleet operations increases, so will the visual coverage of the oceans.

In addition to being of benefit to our country's oceanographic effort, there are other pressing reasons why we should maintain a

strong fishing fleet. It is one of the ironies of our time that peoples of many nations bordering the sea subsist on protein-deficient diets when but a few miles off their shores the sea abounds with food. Although our country has not yet been forced to the sea for additional protein, it is a certainty that at some time in the future this will become a reality. The day for laying claim to the food resources of the ocean has arrived. Our claim must be staked now, for we may never again have the opportunity. To assume that it will be a simple task for us to turn to the sea for our food once the need arises is to overlook the fact that, during our inactivity, other nations will be on the move, making invaluable technological advances that come only with experience, in harvesting the resources of the sea. Already, the rate that fishing fleets of some other countries are growing compared to ours is alarming. Should we falter much longer, the race may be over before we so much as get started.

As fishing pressure continues to mount on tuna stocks, it is obvious that conservation regulations will be needed in addition to those now established for the yellowfin of the eastern Pacific. The United States is setting the example for conservation of this stock of tuna. To continue this leadership into other of the world tuna stocks, our own fishermen should be exploiting these fisheries. We then will have a rightful voice in their management. We have witnessed what lack of management once did to the forest and game resources of our land; let us not allow a similar error to occur in our management of the resources of the ocean.

The tuna fishing fleet now stands poised for further exploratory cruises into regions outside the eastern Pacific Ocean. These explorations have already led to areas of the Atlantic and in a very short time may lead to the central Pacific Ocean. How effective our fishing fleet is in expanding its area of operation may well affect our future well-being and, conceivably, our very survival. It is now time for our country to become more concerned with the efforts of our fleet in its fight for expansion and survival. For it will be a grievous note in our history if the world oceans should someday be devoid of U. S. flag fishing vessels.

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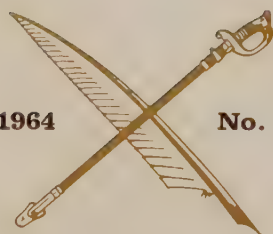
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The Determination and Distribution of Particulate Aluminum and Iron in the Coastal Waters of the Pacific Northwest

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ABSTRACT

The simultaneous spectrophotometric analysis of aluminum and iron with a mixed reagent consisting of ferron and orthophenanthroline was used for the determination of these elements in particulate matter filtered from seawater. The aluminum associated with suspended clay minerals may be used as a sensitive measure of the distribution of runoff plumes in coastal areas. In the coastal waters of Washington and British Columbia, aluminum-rich runoff plumes were enriched also with particulate iron.

Introduction. The bulk of aluminum, one of the more abundant elements in the earth's crust, is present in feldspar rock, where it occurs as aluminosilicates of alkali and alkaline earth elements. The weathering of these rocks brings both aluminum and silicon into solution. Aluminum, however, does not generally remain in the weathering solution; it either precipitates to form aluminum hydroxide or interacts with dissolved silicon to form crystalline, hydrous aluminum-silicate clay minerals.

In coastal seawater, particulate aluminum consists chiefly of aluminosilicates derived from terrigenous clay minerals. Sackett and Arrhenius (1962) proposed particulate aluminum as a promising tracer for the mixing of river water and seawater in the marginal parts of the ocean. Accordingly, in conjunction with an oceanographic study of the Pacific coastal waters off the State of Washington and off British Columbia, Canada, by the Bureau of Commercial Fisheries, measurements of particulate aluminum were included in the analyses of seawater samples collected in the spring of 1963. The purpose of this study was to determine whether the influence of runoff water from the land could be detected readily from the content of aluminosilicate particles in seawater.



Figure 1. Location of sampling stations in the spring of 1963.

Collection and Preparation of Samples. Seawater was collected in two-liter, Van Dorn-type sampling bottles (made of polyvinyl chloride) attached to a stainless-steel hydrographic wire. The location of each sampling station is shown in Fig. 1. Samples were taken at the surface at all stations, and at depth intervals at stations along two lines perpendicular to the coast (Fig. 1).

Two liters of seawater from each sample were filtered through a 47-mm HA Millipore filter (pore size 0.45μ). Following filtration, each filter was placed in a separate plastic vial for storage.

Background of Analyses. Aluminum in water is usually determined by absorption spectrophotometric measurement of the complexes formed in the presence of ammonium aurintricarboxylate (aluminon) or 8-hydroxyquinoline (Sandell 1959). In their work on the distribution of aluminum in the ocean, Sackett and Arrhenius (1962) used the fluorescence of the aluminum complex of Pontachrome Blue-Black R (zinc or sodium salt of 4-sulfo-2-hydroxy- α -

- - - - - AL-FERRON RELATIVE TO REAGENT BLANK
 FE-ORTHOPHENANTHROLINE RELATIVE TO REAGENT BLANK
 ——— REAGENT BLANK RELATIVE TO WATER

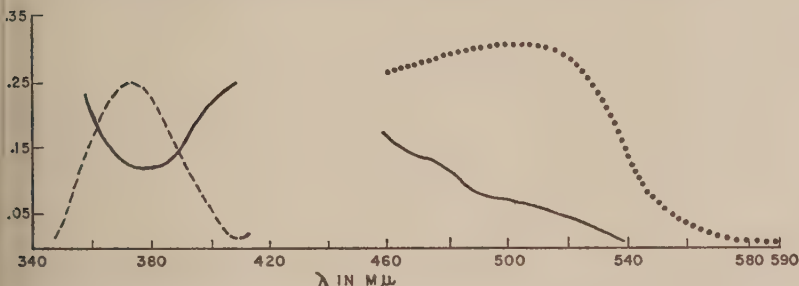


Figure 2. Absorption of the aluminum and iron complexes formed with a mixed ferron-orthophenanthroline reagent.

aphthalene-azo- β -naphthol) to measure both particulate and dissolved aluminum. Davenport (1949) reported that ferron (8-hydroxy-7-iodo-5-quinoline-sulfonic acid), which had been used as a reagent for the determination of iron, formed an aluminum complex which absorbed strongly in the near-ultraviolet portion of the spectrum.

Another method, developed by Rainwater and Thatcher (1960), for the simultaneous determination of both aluminum and iron in water is based on spectrophotometric measurement of complexes of these elements formed in the presence of a mixed reagent containing ferron and 1,10-phenanthroline. Fig. 2 shows the absorption peaks for both complexes developed with this reagent. Although preliminary experiments indicated that this reagent was sufficiently sensitive for quantitative measurements of both elements within the ranges to be expected in the particulate fraction from the two-liter seawater samples, this method did not provide satisfactory determination of aluminum dissolved in seawater. Apparently the aluminum complex was not adequately developed in seawater buffered to the recommended pH (ca. 5), possibly as a result of interference from other dissolved substances. However, when the particulate matter filtered from seawater was fused with sodium carbonate to bring the aluminosilicates into solution, the resulting solution could be adjusted to pH 5 for the satisfactory determination of both aluminum and iron using the ferron-orthophenanthroline reagent.

With a few minor modifications, the Rainwater-Thatcher technique was found to be satisfactory for this study. Although the fluorescence method with Pontachrome Blue-Black R is about 3-4 times more sensitive, the modified Rainwater-Thatcher technique had several advantages: (i) it did not require sensitive fluorimetric equipment, since any good spectrophotometer with a tungsten light source and a light path to about 4 cm is adequate; (ii) Beer's

Law was obeyed over the range of aluminum and iron concentrations observed in the samples ($0-150 \mu\text{g-at/L} \times 10^{-2}$); and (iii) aluminum and iron were determined simultaneously.

Apparatus. Spectrophotometer, Beckman Model DB.

	Al	Fe		Al	Fe
Light source	tungsten	tungsten	Slit width, mm	0.5	0.1
Wave length, $m\mu$	370	520	Cell path, mm	10 and 40	10 and 40

Reagents.

Metal-free water. Pass once-distilled water through a mixed-bed, ion exchange resin column.

Hydroxylamine-hydrochloride reagent. Dissolve 100 g $\text{NH}_2\text{OH} \cdot \text{HCl}$ in metal-free water. Add 40.0 ml concentrated (sp. gr. 1.19) HCl . Add 1.0 $\text{BeSO}_4 \cdot \text{H}_2\text{O}$. Dilute to 1.00 L with metal-free water. WARNING: Beryllium salts in solution are toxic. Do not pipette this solution by mouth.

Sodium acetate, 35%. Dissolve 350 g of anhydrous $\text{Na}_2\text{C}_2\text{H}_3\text{O}_2$ in metal-free water and dilute to 1.00 L.

Ferron-orthophenanthroline mixed reagent. Add 0.5 g ferron and 1.0 orthophenanthroline to 1.0 L of metal-free water. Stir for at least 2 hours with a magnetic stirrer encased in polyethylene. If there are any solids left undissolved, let them settle out and decant the supernate for use.

Aluminum stock solution (1 mg-at/L Al^{+++}). Dissolve 0.474 g $\text{AlK}(\text{SO}_4)_3 \cdot 12\text{H}_2\text{O}$ in metal-free water. Add 0.5 ml CHCl_3 and dilute to 1000 ml with metal-free water.

Aluminum standard solution ($0.1 \mu\text{g-at Al}^{+++}/\text{ml}$). Dilute aluminum stock solution 1:10 with metal-free water.

Iron stock solution (2 mg-at/L Fe). Rinse some analytical-grade iron wire in dilute HCl . Dry and weigh out 0.112 g. Dissolve in a minimum of dilute HCl and dilute to 1000 ml with metal-free water.

Iron standard solution ($0.1 \mu\text{g-at Fe}/\text{ml}$). Dilute iron stock solution 1:20 with metal-free water.

Procedure. Ash the filter containing the aluminosilicate material in a platinum crucible. Fuse the clean, white ash with 1.7 g Na_2CO_3 ; cool and add 3 ml of metal-free water followed by the dropwise addition of 1.0 ml of concentrated H_2SO_4 . CAUTION: Cover the crucible with its platinum lid, leaving only enough room for the tip of the pipette as the H_2SO_4 is added. After the bubbling ceases, add enough metal-free water to dissolve the flux completely. Wash the inside of the platinum lid with metal-free water and add the washings to the crucible content.

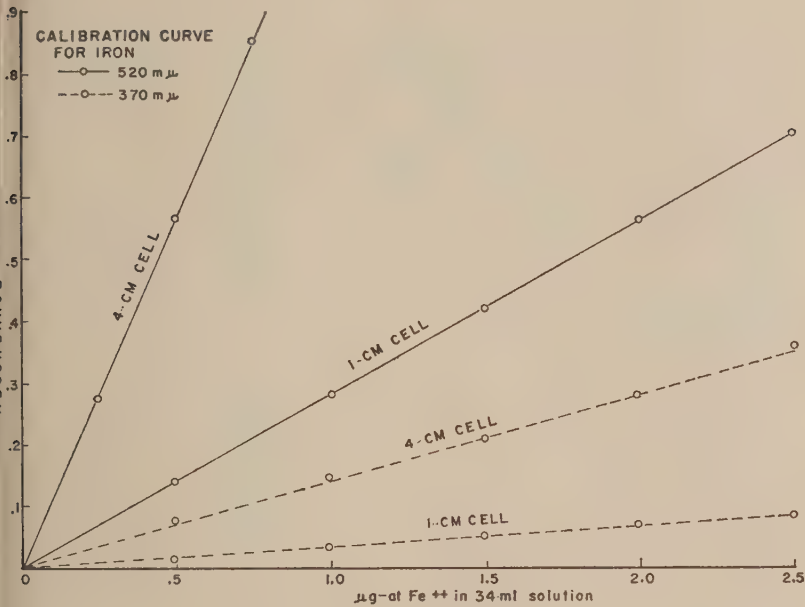


Figure 3. Calibration curve for iron.

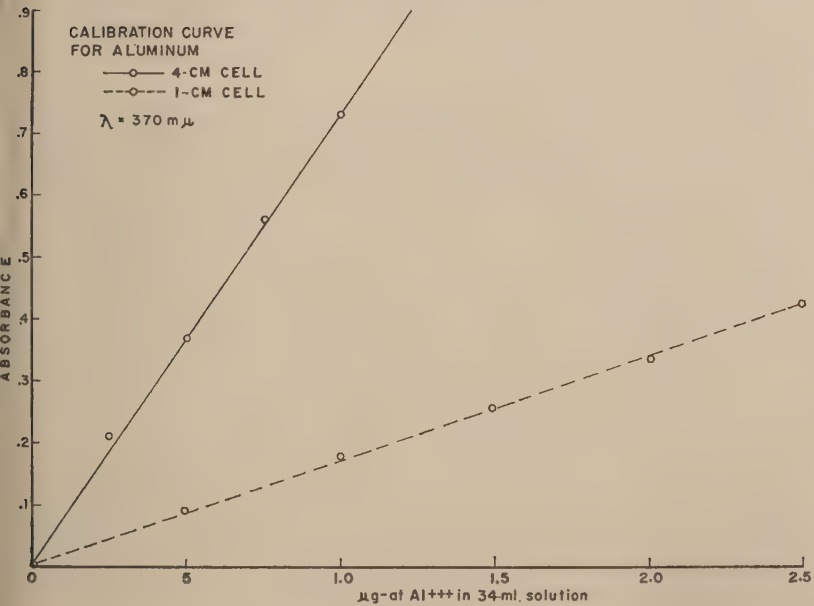


Figure 4. Calibration curve for aluminum.

Transfer the contents of the crucible to a polyethylene graduated cylinder and make up to 20.0 ml with metal-free water. Add 2.0 ml of $\text{NH}_2\text{OH} \cdot \text{HCl}$ and let stand for 30 minutes to reduce any ferric iron.

Add 7.0 ml of sodium acetate buffer followed by 5.0 ml ferron-ortho-phenanthroline solution. Mix and let stand for at least 10 minutes. Measure the absorbance at 370 and 520 $\text{m}\mu$ against a reagent blank.

Prepare calibration curves by combining standards of both elements in the range 0–2.5 $\mu\text{g-at}$ with the reagents in the sequence and in the proportion described above. Measure the iron-phenanthroline complex at 520 and 370 $\text{m}\mu$ and the aluminum-ferron complex at 370 $\text{m}\mu$. Typical calibration curves are shown in Figs. 3 and 4. In the determination for aluminum, subtract the absorbance due to iron at 370 $\text{m}\mu$.

Sensitivity and Precision. The spectrophotometric sensitivity (for 0.001 absorbance), calculated from molar extinction coefficients, is 0.0044 $\mu\text{g/cm}^2$ for aluminum and 0.0059 $\mu\text{g/cm}^2$ for iron. With a 4-cm cell, the limit of detectability is about 0.001 $\mu\text{g-at}$ for both elements.

The spectrophotometric sensitivity based on molar extinction coefficient does not take into account the effect of variability in sample preparation and measurement. A more realistic estimate of effective sensitivity was obtained from the precision of the method. The precision, P , at the 1.00- $\mu\text{g-at}$ level was determined from the standard deviation (s) about the mean of 11 replicate samples. $P = \pm t_{.05} \cdot (s/n^{1/2})$, where P = precision at the 95% confidence level.

For the 11 replicate samples, the values of P were ± 0.02 and ± 0.01 $\mu\text{g-at}$ for Al and Fe, respectively.

Interference. A number of cations give positive interference in the measurement of the aluminum-ferron complex. In his initial investigation of the absorption of this complex in the near ultraviolet, Davenport (1949) showed that, generally, these cations form hydroxyquinolates in slightly acid media. Iron is the principal source of interference, but since it is determined in the analytical procedure, the aluminum determinations are readily corrected for its effects. Fluoride has also been shown to interfere. Rainwater and Thatcher (1960) regarded only lead, cobalt, manganese, and fluoride as being capable of contributing significant interference in the analysis, if they are present in the sample in at least equal proportions with aluminum. Fluoride is a common constituent of clay minerals, in which it substitutes for OH^- groups. The maximum proportion of fluoride in these minerals is about 4% whereas alumina generally comprises from 20% to 40% (Rankama and Sahama 1950). Lead, cobalt, and manganese occur as trace constituents in aluminosilicate clay minerals. Since manganese is sometimes present in seawater as oxide particles (Harvey 1960, Sillén 1961) and is also concentrated by marine organisms (Noddack and Noddack 1939), analyses for this element were conducted on

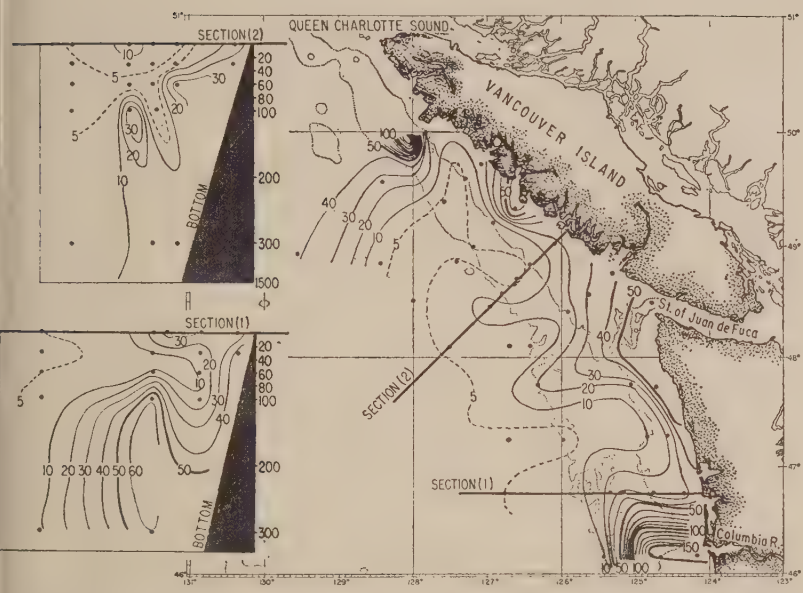


Figure 5. Distribution of particulate aluminum in the spring of 1963 at the surface and along vertical sections in coastal waters of the Pacific Northwest. Contours in $\mu\text{g-at Al/Lx } 10^{-2}$. Depth in meters. Concentrations of particulate aluminum with depth for §§ 1 and 2 are shown in the inserts on the left.

a representative portion of the samples following the aluminum-iron analysis. In all cases, the manganese level was insignificant or below the level of detection for the amount of sample. In the application of this method to the analysis of particulate aluminum in seawater, therefore, interference from these sources should be negligible.

Results and Discussion. Particulate aluminum and iron were determined for two-liter samples of seawater collected off the coasts of Washington state and of British Columbia, Canada, in the spring of 1963. The concentration gradients at the surface for aluminum and iron, respectively, are indicated by the contours in Figs. 5 and 6. The concentrations of aluminum and iron for each water sample analyzed are shown in Table I.

The presence, in the coastal region, of distinct plumes of water rich in particulate aluminum is clearly indicated in Fig. 5. The Columbia River plume is clearly shown; the high values at 100 m and below in section 1 of Fig. 5 at $125^{\circ}20'W$ suggest transport at depth of particulate aluminum northward and westward from the Columbia River. The high surface concentration off Cape Cook near the northwestern extremity of Vancouver Island suggests a

TABLE I. CONCENTRATION OF ALUMINUM AND IRON IN THE SPRING OF 1963 IN THE COASTAL WATERS OF THE PACIFIC NORTHWEST. VALUES GIVEN IN $\mu\text{g-at/L} \times 10^{-2}$.

Stat. No.	Depth m	Al	Fe	Stat. No.	Depth m	Al	Fe
1	0	42	10	24	100	2	2
3	0	23	25	24	300	20	2
4	0	56	22	24	1800	10	1
5	0	130	76	25	0	2	8
6	0	28	37	26	0	4	8
7	0	12	20	28	0	11	6
8	0	6	2	29	0	34	10
10	0	2	21	30	0	35	12
12	0	6	11	31	0	68	24
12	30			33	0	55	18
13	0	2	4	34	0	21	3
14	0	5	4	36	0	20	10
15	0	5	1	38	0	4	1
17	0	6	5	39	0	4	12
18	0	63	12	41	0	10	25
19	0	14	16	42	0	20	22
19	30	16	0	43	0	26	18
20	0	4	8	43	30	42	0
21	0	6	9	44	0	28	4
21	30	3	2	44	30	6	1
21	60	37	0	44	60	7	0
21	100	11	1	44	100	14	1
21	300	9	1	45	0	34	23
21	900	8	2	46	0	22	12
22	0	2	8	46	30	10	0
22	30	4	2	46	60	12	0
22	60	1	1	46	100	60	0
22	100	0	2	46	300	62	0
22	300	4	2	46	1500	12	1
22	1800	137	20	47	0	4	8
23	0	12	4	47	30	6	1
23	30	9	3	47	60	5	1
23	60	2	5	47	100	9	0
23	100	32	1	47	300	9	0
23	300	10	0	47	1500	4	2
23	1500	14	3	48	0	10	2
24	0	8	2	49	0	152	158
24	30	1	1	50	0	150	140
24	60	5	2	51	0	154	133

southward extension of a plume of runoff water from Queen Charlotte Sound. The range of values between 0 and $150 \mu\text{g-at/L} \times 10^{-2}$ demonstrates that the level of particulate aluminum in the sea may be used as a tracer for runoff water.

The dilution of seawater by coastal runoff was resolved with much greater sensitivity by means of aluminum analyses than with salinity data in 1963.



Figure 6. Distribution of particulate iron in the spring of 1963 at the surface in coastal waters of the Pacific Northwest. Contours in $\mu\text{g-at Fe/L} \times 10^{-2}$.

However, from data obtained in 1958 and 1959 over a considerably larger area, Favorite (1961) was able to define distinct plumes of low-salinity water extending seaward from Queen Charlotte Sound and from the Strait of Juan de Fuca. It appears, therefore, that measurement of particulate aluminum would prove useful in defining more precisely the distribution of dilute coastal water in the ocean.

The similarity in the surface distribution of aluminum and iron (Figs. 5, 6) indicates the association, in this region, of high concentrations of particulate iron in the presence of aluminum-rich plumes of runoff water. The fallout of aluminum from these plumes is indicated in Table I by its distribution with depth. On the other hand, it appears from Table I that iron persists near the surface and does not fall out to any appreciable extent, possibly as a result of its utilization by the plankton.

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Some Recent Redfish (*Sebastes*) Publications
ICES/ICNAF Redfish Symposium

GEORGE F. KELLY

SOME RECENT REDFISH (*SEBASTES*)
PUBLICATIONS

ICES/ICNAF REDFISH SYMPOSIUM. The report of the International Redfish Symposium, Copenhagen, October 1959, was published as vol. 150, *Rapports et Proces-verbaux des Reunions* by the International Council for the Exploration of the Sea (ICES), and as Special Publication No. 3 of the International Commission for the Northwest Atlantic Fisheries (ICNAF). 1961. 311 pp. Price \$11.25 Canadian or 75.00 Danish Kr.—The symposium contains 34 complete papers, 10 abstracted papers, and a comprehensive bibliography of literature on *Sebastes* in addition to summary reports of the Symposium Chairman and reports by the Discussion Leaders for each of the five sections.

The format of the report follows the organization of the Symposium and is divided into six sections: (I) Systematics and

natural marks, (II) Redfish distribution, (III) Larval studies and larval distribution, (IV) Sex and maturity, (V) Age and growth, and (VI) Bibliography. Most of the papers deal with studies of species of *Sebastes* in some region of the North Atlantic Ocean, but several concern species of other closely related genera, *Helicolenus* of the Atlantic and *Sebastes* of the Pacific oceans. Papers were contributed by investigators from nine North Atlantic countries.

The Symposium was organized in 1957 by ICNAF and ICES investigators and administrators concerned with the management of the vast international commercial fishery for redfish (marketed as ocean perch) in the North Atlantic Ocean. Information was scant or lacking on many aspects of redfish biology, and divergent views were held by investigators attacking the same problems in different parts of the range. There was general dissatisfaction with nomenclature used in racial studies on both sides of the Atlantic Ocean.

The avowed purpose of the Symposium was to bring together all existing knowledge of *Sebastes* for review and discussion by interested investigators from the countries concerned; the conclusions of the group were to serve in guiding future co-operative studies.

The report is a complete reference source of biological research on *Sebastes*, and, in this respect, fulfills the purpose of the Symposium. All of the earlier literature is cited and virtually all of the significant recent contributions are either abstracted or presented in complete form.

The major problem defined in Section I, systematics, is the general inability of investigators to clearly define the differences among the several types of redfish that are variously represented in the commercial landings. This difficulty proved to be the underlying problem affecting most redfish studies. The morphological papers presented have not provided a comprehensive pattern of *Sebastes* speciation in the North Atlantic Ocean, but they have helped to define the questions that must be answered. Aside from the noncommercial species, *Sebastes viviparus*, there is little agreement among the authors on the taxonomy of the stocks comprising the commercial landings from different parts of the North Atlantic Ocean. Although geographically isolated

groups exist in some areas and can be treated separately in population dynamics studies, throughout much of the North Atlantic Ocean the redfish stocks are inadequately defined, and the relationship of pelagic larvae to adult stocks and the mechanics of stock recruitment are little understood.

In the absence of discrete meristic or morphometric characters for separating the redfish types in much of the area, the studies employing techniques of serological, chromatographic, or other biochemical differentiations are promising avenues of research. Similarly, further investigation of the use of parasitological tags offers promise as a practical tool in redfish stock identification for purposes of population management.

Redfish distribution, the subject of Section II, was covered very completely in a paper by W. Templeman,¹ Discussion Leader of this Section, published just prior to the Symposium. As a result, the report consists of distributional papers completed since Templeman's summary, plus an abstract of his paper. Throughout this Section the value of the distributional information is qualified by the imprecise and subjective nature of the separation between *marinus*-type, *mentella*-type, and other intermediate redfish forms.

Dr. Templeman's paper is a comprehensive summary of what is known about the distribution of larvae and adults of all types of *Sebastes* that have been encountered in the North Atlantic Ocean. The published literature is reviewed thoroughly and the author cited many personal communications canvassed from investigators in other parts of the North Atlantic Ocean concerning *Sebastes* distribution. He reviewed the taxonomy of the group and endeavored to clarify the confused classification with some excellent photographs of typical specimens of *S. viviparus* and the two types of *S. marinus* which, in some instances, he referred to as subspecies, and, at other times, as *marinus*-type and *mentella*-type. Unfortunately, he offered no meristic or morphometric data to show the degree of overlap or the relative frequency of occurrence of forms intermediate between the two types.

¹ Templeman, W., Redfish Distribution in the North Atlantic. Fish. Res. Bd. Canada, Bull. No. 120:1-173. Ottawa, 1959. Price \$1.75 Can.

Templeman discussed the variations in distribution of larvae and adult redfish with respect to a variety of environmental characteristics that may affect the species. He dealt with the general distribution of larvae and fry, distribution of *Sebastes* stocks with respect to the commercial fishery, pelagic distribution of adults, variations in sex composition and size composition, deep-water distribution, day and night vertical migration, and distribution with respect to temperature.

Perhaps the most noteworthy paper in the entire Symposium Report is that by Dietrich, Aurich, and Kotthaus which surveys the hydrography, bottom topography, and biological sampling in the Irminger Sea, the waters between Iceland and Greenland. It contains a great amount of information about the isolated and comparatively unknown marine environment of a newly exploited redfish stock, and is a fine illustration of properly organized fishery hydrographic investigations.

Section III, redfish larval studies, consists of contributions dealing with the identification of larvae, variations in pigmentation, horizontal and vertical distribution, distribution in relation to other plankton organisms, and variations in size composition of larvae with respect to season and depth distribution. Several papers constitute first reports of larval distribution from areas where adult redfish were known to occur but knowledge of larvae was lacking. In the distributional studies several types of sampling devices were used including a variety of slow-speed nets towed horizontally, vertically, or obliquely, and high-speed samplers such as Hardy plankton indicators used in vertical series, Hardy continuous plankton recorders towed at 10 meters from commercial steamers, and the Gulf III sampler and Isaacs-Kidd midwater trawl towed at a series of depths.

The results of these studies show the comparative merits of different sampling gear when employed in similar tasks, and demonstrate the value of specialized samplers for attacking different aspects of the same distributional problem. Although some studies were similar, the results were, for the most part, complementary, each adding to the composite pattern of the horizontal and vertical distribution of *Sebastes* in the whole North Atlantic Ocean.

In the instances where independent studies covered the same areas of ocean there was remarkably good agreement between investigators regarding the relative abundance of larvae and the approximate boundaries of areas of larval concentration.

The results of the Hardy continuous plankton recorder sampling from commercial steamers, reported by Henderson of the Oceanographic Laboratory, Edinburgh, Scotland, demonstrate a means of effective year-round sampling of the distant oceanic areas that are difficult to sample regularly with research vessels. The success of this early work has justified the establishment of additional commercial routes into the western Atlantic Ocean since the time of this Symposium.

The posthumous publication of Dr. Å. Vedel Tåning's descriptions and sketches of the larval and postlarval stages of *Sebastes viviparus* and *S. marinus* are of especial value to those studying larval distribution. These provide, for the first time, a suitable basis for comparison of larvae from areas where more than one type or race of *Sebastes* occurs.

"The Fry of *Sebastes* in Icelandic Waters and Adjacent Seas"² was published shortly after the Redfish Symposium and adds considerably to the earlier studies of Tåning and Templeman. It deals with the distribution, abundance, size composition, and ecology of the planktonic young of *S. marinus* and *S. viviparus* in the vicinity of Iceland. The author described the four plankton communities predominating in the area, and observed that *S. marinus* larvae are confined exclusively to the *Calanus-Thysanessa* community. He concluded that the redfish larvae depend largely on the propagation of copepods for survival in the summer.

The larvae of *S. marinus* comprise about 90 percent of the fish larvae found in the upper waters of the Irminger Sea. Einarsson shows the first evidence that many strong echo-traces from concentrations of planktonic forms are predominantly redfish larvae, and suggests that echograms might be evaluated quantitatively in future surveys.

Einarsson used Tåning's criteria for separating *S. marinus* and *S. viviparus* larvae,

² Einarsson, H., Rit-Fiskideildar, Vol. 2, No. 7:1-67, Reykjavik, 1960.

i.e., the presence of a black tail spot in the smaller specimens of *viviparus* and heavier head armature in the larger individuals, and he encountered no difficulties in separating the two species. He presented the first detailed data on the relative distribution of the two species from waters where both occur.

Even in larval studies the major problem unearthed at the Symposium was one concerning the difficulty of separating species or races of *Sebastes* using objective criteria. Tåning had distinguished *viviparus* larvae by the presence of a black tail spot, *marinus* having none. In the western Atlantic Ocean, Templeman separated *mentella*-type and *marinus*-type redfish by the same characteristic, *mentella*-type having a black tail spot and *marinus*-type having none. Investigators in the Barents Sea, the area where *S. mentella* was first described, could find no other larvae with caudal pigmentation aside from *S. viviparus*. It was the opinion of the meeting that large-scale examinations of pre-extrusion larvae must be carried out before the problem of pelagic *Sebastes* larvae identification could be clarified.

Section IV consists of one paper and two abstracts dealing with sex composition and state of maturity in relation to distribution and migration of redfish. Two of the contributions review present knowledge of the complex spawning cycle of *Sebastes*, i.e., copulation occurs in the fall, the sperm are held within the ovary over winter until spring when the eggs are fertilized, and the viviparous young are spawned a few weeks later. The authors cited data showing variations in sex ratio of bottom-trawl catches and interpreted this as evidence of spawning migrations in the eastern North Atlantic Ocean. They acknowledged the possibility of erroneous interpretation of bottom-trawl data with respect to possible vertical or pelagic movement of bottom-dwelling fish stocks. The need is expressed for further investigation of the occurrence of pelagic redfish concentrations.

In the third paper, Krefft examined the degree of viviparity of species of *Helicolenus* and establishes that genus as intermediate in evolutionary development between the oviparous *Scorpaena* and the viviparous *Sebastes* and *Sebastodes*.

The papers in Section V, age and growth, are generally in accord that *Sebastes* grows

slowly and is long-lived. Most of the studies deal with age reading from otoliths, but age readings from scales, annual progression of modes in the size composition, and growth of tagged fish also were reported. Several contributions referred to an earlier controversy involving an hypothesis of much faster growth, but this appears to be resolved, growth estimates being about 1 to 3 cm per year and ages of 20 to 50 years attained by some fish in most populations. It was the consensus of the group that reading the age of older fish was particularly difficult, and age analysis of commercial stocks for population dynamics studies would progress slowly.

While the problem of racial identity is not treated directly here, it is evident in the nomenclature used. Trout's paper on the growth rate of *S. viviparus* and his note on the structure of *mentella* otoliths from the area where it was first described are steps toward clarification of the racial problem.

Sebastes viviparus grows more slowly than any of the other redfish stocks studied. However, a remarkable reduction in growth rate was caused by tagging among redfish at Eastport, Maine, which resulted in growth even slower than *viviparus*. The studies of Eastport redfish aroused particular interest because of the unusual inshore, shallow-water occurrence of this normally deep-water species which permitted observation of the activities of live redfish for the first time.

In retrospect, the assignment of specific tasks to Discussion Leaders and investigators well in advance of the meeting was perhaps the most important factor responsible for the well-prepared papers and the high degree of participation of those attending. The value of such a gathering should not be underestimated by those charged with the responsibility of assessing the effect of commercial exploitation on fish stocks involved in an international fishery. Aside from the opportunity for personal appraisal of the problems encountered and techniques employed by foreign colleagues, a meeting of this kind aids in establishing guidelines for defining existing problems and initiating cooperative international studies. Such studies are vital for the successful solution of fishery problems arising in nonterritorial waters.—

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Mark-Recapture Experiments With Brown and White Shrimp in the Northern Gulf of Mexico¹

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Abstract

Mark-recapture experiments with commercial shrimps were conducted in the northern Gulf of Mexico during 1962. Results provided information on movements of subadult and adult brown and white shrimp off Texas and Louisiana, on fishing and natural mortality in a stock of brown shrimp fished off Texas, and on growth as well as mortality in the white shrimp resource supporting a major fishery along the Louisiana coast.

INTRODUCTION

A MAJOR GOAL of the Bureau of Commercial Fisheries shrimp research program is to determine optimum levels of exploitation for shrimp stocks in the Gulf of Mexico. To make these determinations, it is first necessary to measure average rates of growth and mortality for each of the stocks concerned. One direct means of estimating these parameters for a particular stock is through the release and subsequent recovery of marked specimens in the area it inhabits, and over which operates the fishery it supports.

Accordingly, a series of mark-recapture experiments was conducted in sections of the northern Gulf of Mexico during 1962 to obtain information on movements, growth, and mortality of brown shrimp, *Penaeus aztecus*, and white shrimp, *P. setiferus*. This paper discusses methods of marking shrimp as well as results obtained from the mark-recapture experiments, and deals only by implication with the general problem of establishing optimum levels of exploitation.

¹Contribution No. 186, Bureau of Commercial Fisheries Biological Laboratory, Galveston, Texas.

METHODS

Description of Marking Agents

Investigations reported by Lindner and Anderson (1956) and by Costello (1959) demonstrated that Petersen disc tags and biological stains can be used to follow the movements and describe the growth of shrimp in their natural environment. Tags, however, appear to be somewhat less desirable marking agents than stains because of the possibility that they interfere with normal growth and movement. Costello (In press) found that certain biological stains do not fade, are therefore easily detectable over long periods of time, and do not seem to affect either the short- or the long-term survival of shrimp. The stain-injection method, because it evidently does not adversely affect marked shrimp, has greatly broadened the scope of research on shrimp population dynamics—particularly in the area of growth and mortality measurement.

Since the inception of the stain-injection technique, Trypan blue and fast green, classified as primary dyes because they concentrate in the gills and are thereby easily seen, have proved to be the only reliable stains for marking shrimp. To increase the technique's overall versatility, a series of laboratory experiments was recently conducted to find additional materials that might serve to provide the shrimp with a supplementary or secondary mark (Klima, MS). These experiments yielded five fluorescent pigments which provided suitable secondary marks when used in conjunction with one of the two biological (primary) stains. Such pigments, which remain at the site of injection and are not obvious to the casual observer, retain full color and are easily detected in the laboratory under ultraviolet light for at least 9 months after application. Their use increases from 2 to 12 the total number of colors, or combinations thereof, that can now be used to mark shrimp. There is no evidence that, when properly injected, the combination of a biological stain and a fluorescent pigment has any short- or long-term effect on survival.

Mark-Release Operations

In areas where experiments were to take place, shrimp to be marked were caught with commercial shrimp trawls towed for less than 15 minutes to minimize injury. As soon as the trawls were emptied, the shrimp were placed in large tanks of circulating sea water to be sorted and marked.

Shrimp were marked with either fast green or Trypan blue stain alone, or in combination with a fluorescent pigment, following the methods described by Costello (In press) and Klima (MS), respectively. Aqueous solutions of 0.5% fast green or 0.25% Trypan blue provided the primary marks, while a 1.2% mixture of the fluorescent pigment blaze orange in petroleum jelly constituted the secondary mark. When double marks were applied, the shrimp were first injected with one of the biological stains and then immediately injected with the fluorescent pigment. Other shrimp were tagged with Petersen disc tags (5/16-inch diameter and 0.02-inch thickness) to acquire additional information on movements.

Estimation of growth rates from mark-recapture experiments requires that the release size of the experimental individuals be known. Since the identity of individual shrimp cannot be maintained when employing the stain-injection method of marking, shrimp to be stained were first sorted on the basis of uniform size into several narrowly defined length classes (± 5 mm total length). Each class was subsequently identified by means of a primary stain or a

combination of primary and secondary stains. In experiments where growth estimation was not an objective, shrimp were marked without being selected for uniformity of size.

After marking, the experimental shrimp were held from 12 to 24 hours before release. Just prior to release, all specimens in poor condition (i.e., overstained, injured, or disoriented) were discarded. All marked shrimp were liberated on the bottom in groups of 100 by means of a special release box. Underwater observations during earlier mark-recapture experiments on the Tortugas fishing grounds revealed that experimental shrimp so released immediately burrow into the substrate. Thus, predation during the process of liberation can, for most practical purposes, be assumed to have been non-existent. Because of the care taken in their handling, the number of marked individuals liberated at the start of each experiment was considered to be a valid measure of the initial size of each experimental population.

In all experiments involving specimens marked with biological stains, the areas of release ranged in size from 30 to 210 square miles. It was therefore not possible, upon analyzing subsequent returns, to determine the exact distances moved by individual stained shrimp. To minimize this difficulty, the center of the release area was considered to be the specific site of release. This problem did not exist in the case of the tagged shrimp since the release position of every individual was known.

Recapture and Return of Marked Shrimp

A reward of \$2 was paid for the return of each marked shrimp accompanied by information regarding the date and the place where it was recaptured. All shrimp processing plants located in the study areas were provided with posters describing the program, and with bottles containing formalin in which recaptured shrimp could be held.

Estimates of the total fishing (recapture) effort expended in experimental areas were computed from *Gulf Coast Shrimp Data* published monthly by the Bureau of Commercial Fisheries, and from supplementary data collected by the Bureau's statistical agents. The average number of hours fished per vessel trip for either 14- or 30-day periods (depending on the experiment) was projected from data gathered through interviews with vessel crews.

RESULTS

Brown Shrimp, April, 1962

A total of 2,431 stained brown shrimp was released in a 100-square mile area southeast of Pass Cavallo, Texas, in water which ranged from 21 to 24 fathoms. Two groups of tagged shrimp, consisting of 976 and 716 individuals, respectively, were released—one on each side of the stained group—in statistical fishing areas 18 and 20 (Table 1, Fig. 1). Of the stained shrimp released, 153 (6%) were recovered through February, 1963, while 87 (5%) of the tagged shrimp were recovered through December, 1962.

Recoveries from the stained group were sufficient to estimate mortality rates for the period April-June, provided that certain assumptions could be satisfied. One of these was that the marked shrimp did not migrate out of the designated fishing area during this period.

MOVEMENTS: The pattern of recoveries from April through June indicated that the stained shrimp distributed themselves between the 16- and 30-fathom

TABLE 1
RELEASE AND RECOVERY INFORMATION ON MARK-RECAPTURE EXPERIMENTS
WITH SHRIMP IN THE NORTHERN GULF OF MEXICO, 1962

Species	Type of mark	Release data				Recapture data	
		Total length in mm.	Date	Area	Depth in fathoms	Number	Percent
Brown	Fast green	125-225	4/2-4/62	SE Pass Cavallo, Tex., Stat. area 19	21-24	2,431	153 6.3
Brown	Petersen disc tags	115-220	4/6-7/62	SE Port Aransas, Tex., Stat. area 20	20-27	716	69 9.6
Brown	Petersen disc tags	137-211	4/8/62	SSE Freeport, Tex., Stat. area 18	21	976	18 1.8
Brown	Fast green	109-118	7/8-12/62	S Grand Isle, La., Stat. area 13	13-16	1,554	437 28.1
	Fast green and blaze orange	124-133				720	187 26.0
Brown	Trypan blue	90-154	7/17/62	S Galveston, Tex., Stat. area 18	4-8	1,840	49 2.7
	Trypan green and blaze orange	98-107				1,133	25 2.2
White	Fast green	147-156	9/23-26/62	SW Vermillion Bay, La., Stat. area 16	3-5	1,071	65 6.1
	Fast green and blaze orange	147-156				843	11 1.3
White	Trypan green and blaze orange	115-124	9/28-29/62	Cameron, La., Stat. area 17	3-5	792	44 5.6
	Trypan blue	134-143				1,499	158 10.5

depth contours over approximately the same general area in which they were released. More than 99% of those recovered were caught within the 25-fathom contour, with none being taken beyond 30 fathoms (Table 2). Since less than 200 hours of fishing effort were expended at depths greater than 30 fathoms, it was not possible to determine whether significant offshore movement occurred during this period. The distribution of recoveries in the experiment's later stages (July-February) suggested little offshore movement, for few marked shrimp were recaptured at greater depths even though considerably more fishing effort was expended there. All told, these data indicate minimal offshore movement from April through June. In reference to movements inshore, more than 7,000 hours of commercial fishing effort expended at depths of less than 15 fathoms through June resulted in the recapture of only one shrimp, indicating that such movements were also minimal. The pattern of recoveries indicates that the depth distribution of tagged shrimp was similar to that of the stained group (Fig. 1).

TABLE 2
DEPTH DISTRIBUTION OF RECAPTURED (STAINED) BROWN SHRIMP AND
CORRESPONDING TOTAL FISHING EFFORT (IN THOUSANDS OF HOURS) —
TEXAS GULF COAST, APRIL, 1962

Period	April - June		July - February	
Depth in fathoms	Number recovered	Fishing effort	Number recovered	Fishing effort
11-15	0	7.3	1	159.3
16-20	68	13.4	2	118.4
21-25	70	8.0	8	44.4
26-30	1	1.0	2	31.0
31 & over	0	0.2	1	2.3

More than 90% of the marked recaptures were taken within 30 miles of their sites of release. The longest movement was about 70 miles. Examination of the average distance traveled revealed that the marked shrimp did not move greater distances with increased time at large. Several shrimp at liberty for more than 180 days had traveled an average of only 17 miles, whereas shrimp that were recaptured within 180 days had traveled a mean distance of 16 miles. What little movement occurred appeared to be parallel to the coast between the 16- and 30-fathom depth contours.

MORTALITY: The following formulae, as derived by Beverton and Holt (1957), were used to estimate mortality coefficients for the stained shrimp population during the period April through June:

$$F = \frac{\frac{n_1}{\gamma} \log_e \left(\frac{n_1}{n_2} \right)}{N_0 \left(1 - \frac{n_2}{n_1} \right)}$$

$$X = \frac{1}{\gamma} \left[\log_e \left(\frac{n_1}{n_2} \right) \right] \left[1 - \frac{n_1}{N_0 \left(1 - \frac{n_2}{n_1} \right)} \right]$$

where F is the instantaneous mortality rate caused by fishing; X is the instantaneous rate of loss attributable to all other causes, including natural mortality, marking mortality, emigration, and failure of the fishermen to return recaptured marked shrimp; n_1 and n_2 are the calculated numbers of recoveries during the experiment's first and second time periods; N_0 is the number of marked shrimp released; and γ is the length of a time period.

The value of X provides an estimate of natural mortality when losses due to other factors are negligible. In the present experiment, care exercised during staining and releasing operations insured that mortality due to marking and to predation during release was minimal. Evidence cited above indicates that losses of stained shrimp due to emigration from the study area were also probably unimportant. No estimate of losses caused by failure of fishermen to recover from or to report stained shrimp in their catches is available, but this type of error is believed to have had little influence on experimental results because of sustained efforts to maintain fisherman-interest in the recovery of marked shrimp. Accordingly, it seemed reasonable to assume that a constant proportion of stained shrimp caught during each interval of the experiment was reported. Even if the proportion of nonrecovered individuals constituted as much as 20% of the total number recaptured in each interval, the resulting estimate of F would have differed by only four units in the second decimal place from the value obtained and employed below.

The 80% confidence intervals presented in Table 3 indicate no significant change in fishing effort during the study period, thereby making it unnecessary to adjust the number of recoveries from each time interval to a uniform effort. Recovery information from three 30-day time intervals, covering the period from April 3 to July 2, 1962, proved sufficient to calculate estimates F and X . When converted to monthly rates of reduction, these estimates suggested that 21% of those shrimp present at the beginning of a month died before the end of that month as a result of commercial fishing activities, whereas 60% died during the same period from natural causes.

Brown Shrimp, July, 1962

Stain-marked brown shrimp were released near Grand Isle, Louisiana, and off Galveston, Texas, in July (Table 1). Although the experiments were undertaken to obtain information on movements, growth, and mortality, these objectives were only partially achieved. In both instances, more than 90% of the stained shrimp recovered were caught within 10 days of release. The unusually short recovery periods are attributed to the small size of the areas in which the marked shrimp were released and to movements of the commercial fleet from these areas as the experiments progressed.

TABLE 3

RECOVERIES OF STAINED BROWN SHRIMP AND RELATED FISHING EFFORT
(IN THOUSANDS OF HOURS) DURING THE APRIL, 1962, EXPERIMENT
OFF THE TEXAS GULF COAST

Time period (30-day intervals)	Number recovered	Fishing effort
1	99	7.9 $\pm$ 1.3
2	30	7.3 $\pm$ 0.6
3	10	7.2 $\pm$ 0.1

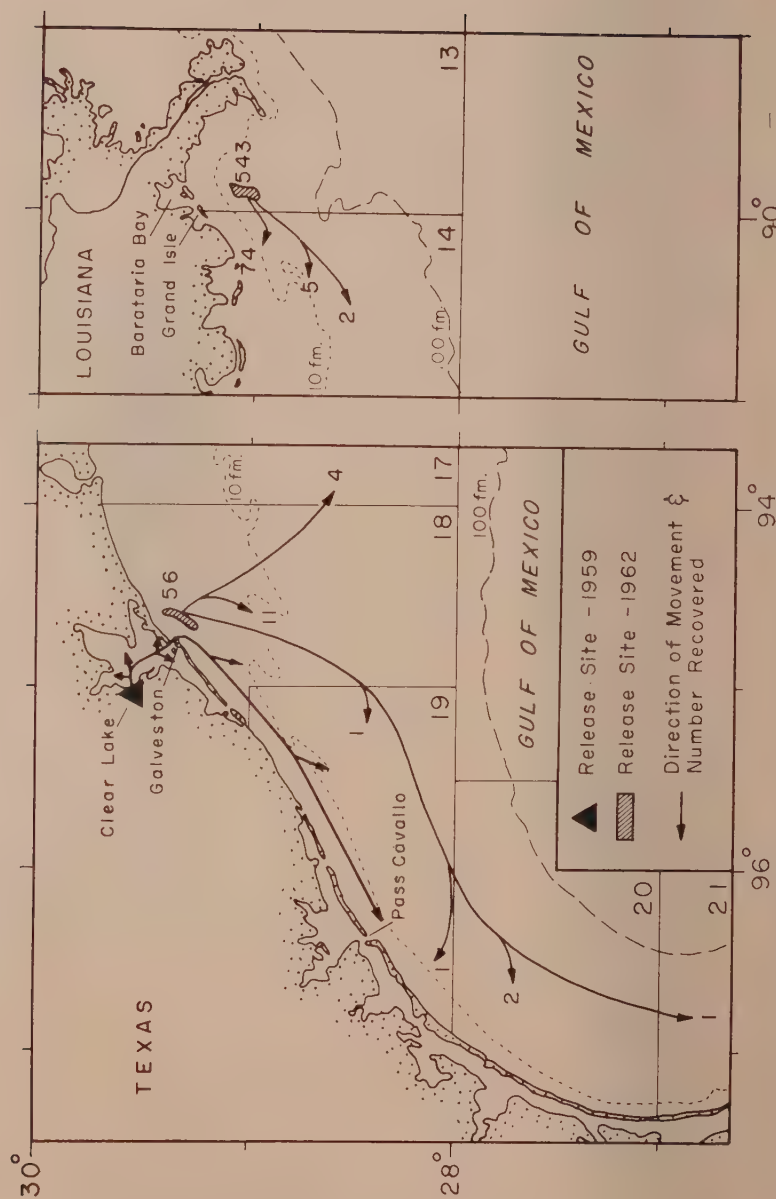


Fig. 2. Movements of marked brown shrimp recaptured off the Texas-Louisiana coast.

MOVEMENTS: More than 98% of the shrimp recovered from the Louisiana experiment were recaptured within 30 miles of the release area, the remaining 2% having moved less than 60 miles (Fig. 2). Movements were seaward and generally to the west.

Because of a combination of low fishing intensity and a state law which prohibited the landing of brown shrimp smaller than 30-count heads-on, less than 3% of the 2,973 marked shrimp released off Galveston were eventually recovered. Most individuals in this group were smaller than the legal size permitted in Texas, and almost 80% of those recovered were caught by boats which landed their shrimp at Louisiana ports where no size law was in effect. Over 88% of the marked shrimp recovered from the Texas experiment were caught within 30 miles of the area of release, while 6% had traveled more than 60 miles in a southwesterly direction (Fig. 2). The greatest distance recorded was 195 miles. An earlier experiment initiated in Galveston Bay resulted in four marked brown shrimp being recaptured in the Gulf between Galveston and Pass Cavallo (Ingles, 1959). Results of both the experiments conducted in Texas waters indicate that small brown shrimp which leave Galveston Bay are recruited to the fished population along most of the Texas coast.

The shrimp released at the beginning of the Louisiana and Texas experiments were marked with either a biological stain or with a combination of a biological stain and a fluorescent pigment. Since this was the first time the combination mark had ever been used, it was of interest to compare recovery rates of shrimp bearing the "single" mark with those bearing the "double" mark. The marked groups compared herein were subjected to similar conditions and otherwise treated in like manner except for the type of mark applied. A comparison of the number of returns of shrimp with the two types of marks yielded Chi-square values of 0.529 and 1.233 with 1 degree of freedom for the Texas and Louisiana experiments, respectively. These values are not significant at the 5% level, and the hypothesis that there was no difference in the recoverability of the two types of marks is accepted.

White Shrimp, September, 1962

A total of 4,205 marked white shrimp was released in statistical areas 16 and 17 off the western Louisiana coast in depths of 3 to 5 fathoms (Table 1, Fig. 3). To obtain information on growth, the marked shrimp were released in three lots, each consisting of individuals selected on the basis of uniform length and grouped accordingly (Table 1). Overall recoveries comprised 292 (9%) of the shrimp released in the Cameron area and 76 (4%) of those liberated off Vermilion Bay.

MOVEMENTS: Ninety-seven percent of all recoveries were made between September and December. Considering only recoveries during this period, there appeared to be limited movement of the marked shrimp between the two release areas. More than 88% of the recoveries were taken within 30 miles of each area, with the greatest distance traveled approaching 80 miles. Three shrimp were recovered in February and March (1963) east of the release areas off Eugene Island, Louisiana, one having traveled 70 miles and the others more than 120 miles.

MORTALITY: When originally conceived, this experiment was designed to provide estimates of mortality rates for each of the three groups of marked white shrimp released. Complexities of the fishery and other shortcomings in the data

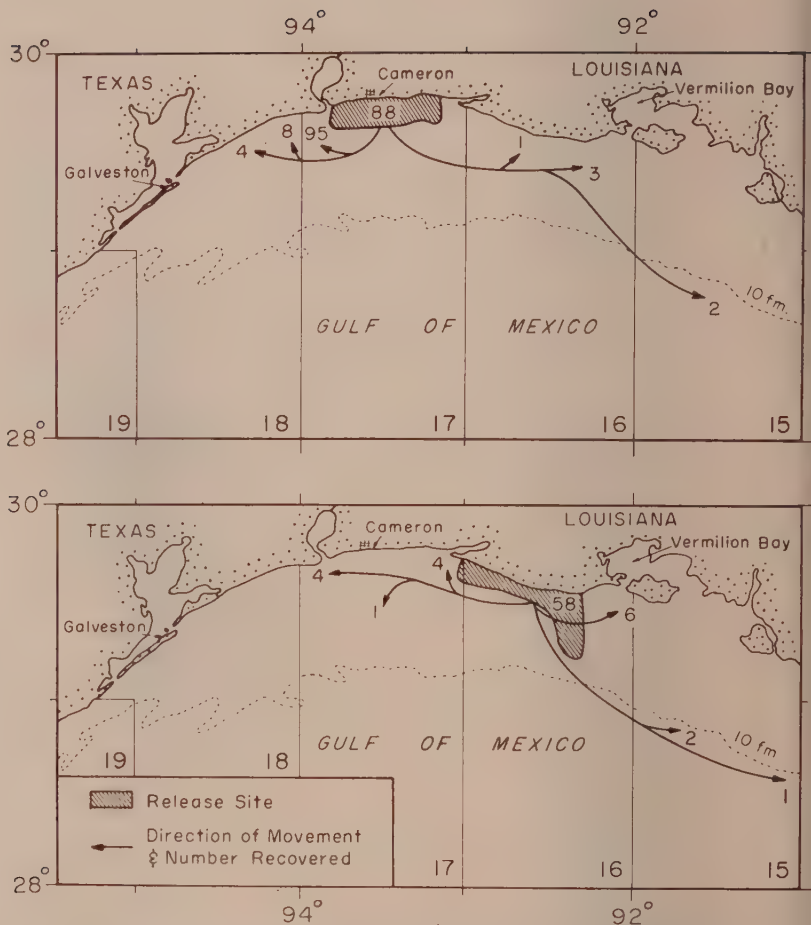


FIG. 3. Movements of marked white shrimp recaptured from September, 1962, through March, 1963, off the Louisiana Gulf coast.

made it possible, however, to derive for only one group an estimate of its total mortality rate which could not be separated into the components of major interest. Although this value has limited practical use, it does indicate the general level of mortality to be expected in an exploited group of white shrimp.

If losses of marked shrimp due either to the failure of fishermen to report recaptured individuals or to emigration from the study area are not constant throughout the recovery period, mortality estimates will be biased. But, because of the high degree of publicity associated with the study and the small amount of emigration suggested by the recovery patterns, it was concluded that the effects of such factors could be considered of minor importance in the present case. Adjustment of the number of recoveries to unit fishing effort from each

14-day interval was necessary, however, since expenditures of effort by the shrimp fleet in the study area were not uniform during the period of interest (Table 4). A regression line fitted to the natural logarithms of the corrected number of recoveries yielded an instantaneous total mortality rate of 0.92. Transformation of this value to a 14-day rate of decline gave an estimate of 60%.

TABLE 4

RECOVERIES OF STAINED WHITE SHRIMP ADJUSTED TO UNIT FISHING EFFORT
(IN THOUSANDS OF HOURS)—LOUISIANA GULF COAST,
SEPTEMBER - NOVEMBER, 1962

Time periods (14-day intervals)	Number recovered	Fishing effort	Recoveries adjusted to unit fishing effort
1	77	9.46 $\pm$ 1.5	75.7
2	34	10.72 $\pm$ 1.7	29.5
3	10	7.72 $\pm$ 1.8	12.0

GROWTH: Recovery data from the three size groups released in September, 1962, proved suitable for measuring the average growth rate of late subadult and adult white shrimp during the fall season (Table 5). Ideally, growth calculations should be made for each sex. In the present instance, however, the number of shrimp recovered during each time interval of the experiment was insufficient to permit this refinement. To obtain valid estimates from data which include both sexes, it is necessary that the sex ratios of recaptures remain constant throughout the experiment. A Chi-square test indicated that such was the case during the study being described (X^2 with 15 degrees of freedom = 21.4; $X^2_{.95} = 25.0$).

TABLE 5

AVERAGE WEIGHTS (IN GRAMS) AT RECAPTURE OF WHITE SHRIMP (SEXES
COMBINED) REPRESENTING THREE SIZE GROUPS—LOUISIANA GULF COAST,
SEPTEMBER - NOVEMBER, 1962

Group Time periods (7-day intervals)	A		B		C	
	Average weight	Number	Average weight	Number	Average weight	Number
1	13.3	20	20.0	46	27.3	4
2	14.5	10	21.8	48	28.3	13
3	17.0	4	23.9	26	30.1	16
4	19.6	4	27.0	16	31.6	25
5	20.9	5	28.2	13	35.5	3
6					36.5	4
7						
8					41.1	4

Recoveries from each of the three narrowly defined length classes were grouped into successive 7-day units, after which the von Bertalanffy growth-in-weight equation (Beverton and Holt, 1957) was used to describe their growth. Estimates of two of the parameters of the growth equation, W_{∞} and K , were obtained by fitting a line to a Walford plot of the resulting average

weights. The parameter t_0 was determined by conventional means, wherein the age at release of the smallest shrimp used in the experiment was estimated to have been 12 weeks. The equation describing the growth of adult white shrimp during the period from September to November was found to be:

$$w_t = 87 \text{ g} \left(1 - e^{-0.12[t - (-0.57)]} \right)^3$$

Although this equation is based on data from a relatively brief period in the white shrimp's overall growth history, it imparts information of particular interest in studies of the species' dynamics because it describes growth during that portion of the life history (and season) when exploitation of the white shrimp is greatest.

Calculations based on the above equation indicate that white shrimp increase in size during the fall from 54-count, heads-off (120 mm) to 33-count (141 mm) in 4 weeks, and to 23-count (159 mm) in 8 weeks. A comparison of these results with growth measurements for female white shrimp reported by Lindner and Anderson (1956) reveals close agreement (Table 6). It should be pointed out, however, that these authors estimated a somewhat lower growth rate when they employed data wherein the sexes were combined.

SUMMARY

Adult brown shrimp, *Penaeus aztecus*, marked with biological stains or Petersen disc tags, were released off the Texas coast in April, 1962. Recoveries from this experiment indicated that movement was parallel to the coast and confined to depths between 16 and 30 fathoms. Comparisons of the distance traveled over time revealed that most of the marked shrimp remained within 30 miles of the release site. The greatest distance traveled was about 70 miles. Analysis of the recovery data indicated that fishing mortality was 21% and mortality due to natural causes was 60% per month during the period from April through June.

TABLE 6

COMPARISON OF CALCULATED LENGTHS (MM) OF WHITE SHRIMP (SEXES COMBINED) FROM THE SEPTEMBER, 1962, MARK-RECAPTURE EXPERIMENT OFF LOUISIANA WITH THOSE OF FEMALES REPORTED FOR THE SAME AREA AND SEASON BY LINDNER AND ANDERSON (1956)

Time in months	Total length from Lindner and Anderson	Total length from mark-recapture experiment, Sept., 1962
0	120	120
1	143	141
2	160	159
3	172	172

Small brown shrimp, marked with biological stains and fluorescent pigments, were released off Grand Isle, Louisiana, and Galveston, Texas, in July, 1962. Again, a large proportion of the recoveries were taken within 30 miles of the release areas. The longest distance traveled was 195 miles.

White shrimp, *P. setiferus*, representing several restricted size groups, were marked with biological stains and released in two adjacent areas off the

Louisiana coast in September, 1962. The distribution of recaptures indicated limited movement of the marked groups between the two areas and little or no offshore movement. Analysis of the recovery data revealed that during September-November total mortality was 60% per 14-day period. After fitting the von Bertalanffy growth function to the mean weights of the recaptured shrimp (sexes combined), it was estimated that, during the fall of the year, white shrimp in this area required 2 months to increase in size from 54-count, heads-off (120 mm) to about 23-count (159 mm).

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the many scale characters examined were affected by these factors to varying degrees. It was also stated that preliminary examination of population interrelationships using a set of meristic characters and scale characters least affected by age differences indicated separation of most of the Asian and North American chum populations sampled in 1959. However, chum salmon from Siberian populations and those sampled from the Kotzebue area in northwest Alaska had similar characteristics.

In 1963, the differences between Asian and North American chum populations were further examined. In order to obtain separation of the Siberian and Kotzebue area chum salmon and generally improve definition of the overall Asian-North American population interrelationships, it was necessary to use meristic characters for which data were collected only in the years 1958–62. Also, sampling of whole chum specimens from which the meristic data are collected was reduced in 1960 and terminated in 1963. Consequently, coastal samples of use in representing Asian and North American chum meristic scale morphotypes are essentially limited to those collected in 1958 and 1959.

Brood year and age at maturity differences are apparently reflected in the characters used. Therefore, only high seas chum salmon estimated to be the matures of 1958 and 1959 can reasonably be compared to the 1958 and 1959 coastal morphotypes to determine the continent of origin. High seas chum salmon attaining maturity in years other than 1958 and 1959 may have significantly different characteristics.

CHUM SALMON MORPHOLOGICAL STUDIES

by John LaLanne

Research on the problem of determining the continent of origin of high seas chum salmon by means of morphological characters continued in 1963 along the following lines: (1) Evaluate the differences between Asian and North American chum populations as obtained by the use of a combination of scale and meristic characters; (2) Attempt to determine the continental origin of high seas chum salmon by comparing their meristic-scale characteristics to those of chum of known Asian and North American populations.

As previously reported (INPFC Annual Report, 1962), whereas few of the meristic characters differed between brood years and ages at maturity, most of

For these years, using combined meristic and scale characters, the separation of the Asian and North American chum populations is such that useful information regarding the continent of origin of high seas chum salmon can be obtained. It is planned to present the method in a later report that will essentially conclude the combined meristic-scale Protocol research on chum salmon by the United States.

MARINE GROWTH OF WESTERN ALASKAN SOCKEYE SALMON (*ONCORHYNCHUS NERKA* WALBAUM)

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ABSTRACT

The study is based on weight, length, age and maturity data on individual sockeye salmon (*Oncorhynchus nerka*) taken by gill-nets from 1956 through 1960 in the North Pacific Ocean and Bering Sea. Preliminary to estimating growth rates within and between certain marine life history stages, the effects of the following sources of variation are considered: (1) sex, maturity and waters at sea before capture; (2) continent of origin; (3) changes in size between time of capture and time of laboratory processing; (4) use of gillnets known to be selective for size; (5) area of capture; and (6) year of capture.

Seasonal increases in average body weight of Western Alaskan sockeye salmon are found to be 30 percent for 1-winter immatures during 40 days in July-August, 22 percent for 2-winter immatures during 50 days in July-August, 13 percent for 2-winter maturing fish during 40 days in May-July, and 14 percent for 3-winter maturing sockeye salmon during 30 days in May-June.

With average body weight of 1-winter immatures on August 3 as a reference, estimated long-term increases are as follows: 149 percent until July 30 the next year as 2-winter immatures, 247 percent until June 14 the next year as 2-winter maturing sockeye, and 382 percent until June 10 the second year later as 3-winter maturing sockeye. Between July 30 as 2-winter immatures and June 10 the following year as 3-winter maturing fish, average body weight of Western Alaskan sockeye salmon is estimated to increase by 94 percent.

Percentage rates are converted to total and 30-day average instantaneous rates. Also discussed is the need for future research on short-term ocean growth and natural mortality rates of Pacific salmon, particularly as knowledge of these parameters relates to sustainability of fishing salmon on the high seas.

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INTRODUCTION

Growth of Pacific salmon (*Oncorhynchus* spp.) during short intervals of their life at sea has seldom been a major concern of management. So long as the stock is exploited only during maturation in inshore waters, focus is on manipulating the return to achieve reasonable balance between escapement and catch, and therefore to attain maximum yield insofar as is practicable. When maturing or immature salmon are also exploited offshore, however, short-term rates of ocean growth and mortality will fix the time and area of harvest that best approximate maximum yield from a given recruitment. Knowledge of both parameters may then become vital to management of the resource.

Parker and Kirkness (1956) and Parker (1960) were the first to publish on this balance between ocean growth and mortality in the salmon. The latter report concludes maximum yield for king salmon (*O. tshawytscha*) at current fishing intensity would be best approximated by abolishing size limits in the troll fishery, by encouraging use of non-selective gear and, through time and area restrictions, by harvesting only maturing fish. In terms of biomass, growth was believed to exceed mortality throughout the life of a brood.

In maturing Asian chum (*O. keta*) and sockeye (*O. nerka*) salmon, Taguchi (1961a, 1961b) investigated rates of growth and mortality from the time of recruit-

ment to a high seas gillnet fishery until inshore appearance of survivors on the spawning migration. That author computed higher rates for natural mortality than for growth. Therefore, he concluded offshore fishing approximates maximum yield more closely than inshore fishing.

On the other hand, Ricker (1962) inferred that oceanic harvest of maturing sockeye would yield from 6 to 40 percent less weight than inshore exploitation of the same North American stocks. Calculated weight loss from offshore fishing the year before maturity was from 50 to 65 percent. For both periods of ocean life, growth was shown to exceed the computed maximum values for natural mortality.

Growth is unquestionably the easier to estimate. Scales, or direct observations on fish size, are available from commercial or research operations at sea or ashore. Yet all methods of using the data raise problems.

In his informative review of life history studies on sockeye salmon of the Far East, Hanamura (MS) notes two causes of difficulty. First, growth differs between segments of a brood maturing in successive years; to presume that annual ocean growth is simply the difference between average size-at-age of spawners, although much data on spawners may be available, is a serious mistake. Secondly, failure to define the relationship between fish length and scale radius from data taken throughout the life span can cause observed and calculated lengths to contradict one another.

In tagging studies, necessarily hurried measurement of live releases (e.g., Parker and Kirkness, 1956; Koo, 1959) or inaccurate measurement of dead recoveries, perhaps by observers not thoroughly trained, can bias estimates of growth. While observations showing larger size at release than at recovery are commonly discarded (e.g., Koo, 1959), accuracy of remaining records is seldom known. Moreover, effects on growth from handling or from the tag itself cannot be examined in direct and simple fashion. These factors mar the intuitive appeal of successive observations on size of individual fish. Finally, the recoveries may be too few to estimate growth rates with high precision.

The present study is based on weight and length data from individual fish. A major part of the study is an effort to account for the following sources of variation: (1) sex, maturity and winters at sea before capture; (2) changes in size between time of capture and time of laboratory processing; (3) area of origin; (4) use of gillnets known to be selective for size; (5)

area of capture; and (6) year of capture.

Background material (Fukuhara *et al.*, 1962) provided means of separating Western Alaskan from Asiatic sockeye salmon. However, probabilities of misclassifying individual fish taken on the high seas were unknown. Therefore, it was necessary to establish certain criteria for investigating possible size differences by area of origin; if present, such differences could bias estimated growth rates for the target stock. Similarly, the theory of gillnet selection was used in judging effects of mesh selectivity in present data. Sampling coverage imposed important limitations on evaluating effects of area and annual variation in size.

The type of data, the sources of variation, and the availability of background information led to problems or methods not commonly considered in studies of marine growth in fishes. Solutions given here are not presumed to be final. Rather, the objective is to provide a basic description of growth in weight of sockeye salmon of Western Alaska. A secondary objective is to stimulate further research on short-term ocean growth and mortality of Pacific salmon.

Various research groups at the Bureau of Commercial Fisheries Biological Laboratory, Seattle, Washington, provided data for the present study. The High Seas Salmon Research Unit collected most specimens and supplied fork lengths of fresh fish to investigate the effects of mesh selection. The laboratory of the Morphology Unit procured length, weight and maturity data. The Age Analysis Unit determined ages from scales. Data were punched on cards by the Biometrics Unit, which also provided machine processing.

For stimulating criticism of the manuscript, we wish to thank Drs. R. R. Parker and W. E. Ricker of the Fisheries Research Board of Canada Biological Station at Nanaimo, B. C., and the following scientists at the Bureau of Commercial Fisheries Biological Laboratory at Seattle, Washington: G. Hirschorn, D. D. Worlun, F. M. Fukuhara and H. H. Shippen.

COLLECTION AND PROCESSING OF SPECIMENS

Annual reports of the International North Pacific Fisheries Commission (INPFC, 1957-1961) for the years 1956 through 1960 describe the national source area and sample size for whole sockeye salmon collected annually for the United States from the North Pacific Ocean and Bering Sea. Capture was by gillnet. Taken primarily for racial studies, these samples a-

TABLE 1. Mesh size composition of gillnets used and mean effort of Japanese and United States research vessels and of Japanese commercial vessels for the years 1956 through 1960.

Country and year	Mesh size and average no. of gear units fished ¹ per set										
	2.50"	2.98"	3.25"	3.58"	4.18"	4.50"	4.77"	4.80"	4.89"	5.25"	5.37"
<i>United States research vessels</i>											
1956	3	—	3	—	—	6	—	—	—	6	—
1957	4	—	4	—	—	12	—	—	—	4	—
1958	4	—	4	—	—	12	—	—	—	4	—
1959	4	—	4	—	—	24	—	—	—	4	—
1960	4	—	4	—	—	24	—	—	—	4	—
<i>Japanese research vessels</i>											
1956	—	4	—	4	7	—	92	—	—	—	5
1957	5	—	4	—	—	15	**	—	—	5	—
1958	2	—	2	—	—	6	—	—	40	2	—
1959	4	—	4	—	—	4	—	25	25	4	—
1960	4	—	4	—	—	12	—	60	—	4	—
<i>Japanese commercial vessels</i>											
1956	—	—	—	—	—	—	—	293	—	—	—
1957	—	—	—	—	—	—	—	293	—	—	—
1958	—	—	—	—	—	—	—	293	—	—	—
1959	—	—	—	—	—	—	—	293	—	—	—
1960	—	—	—	—	—	—	—	293	—	—	—

¹ U. S. research vessels: Shackles—one shackle is approximately 300 feet in length. Japanese research vessels: Tans—one tan is approximately 300 feet in length for 2.50", 3.25", 4.50" and 5.25" meshes; for other mesh sizes it is approximately 180 feet in length. Japanese commercial vessels: Tans—one tan of Japanese commercial gear is approximately 180 feet in length.

** Average number of tans fished not available.

The general source of the data used herein. The data are tabulated in basic data tables, a list of which is given on page 31. Interested persons can obtain these basic data tables by writing to the authors at the Seattle Biological Laboratory of the Bureau of Commercial Fisheries (2725 Montlake Boulevard, Seattle, Washington 98102).

Table 1 gives the mesh size composition of gillnets used by year, along with mean effort per vessel of Japanese and United States research vessels and of Japanese commercial vessels. Research sections of the INPFC annual reports provide a more detailed classification by vessel, position and time.

SHIPBOARD PROCEDURES

Gillnetting and data collection procedures aboard United States research vessels changed very little from 1956 through 1960. The sequence of operations was as follows:

- (1) Gillnets were set in the evening and hauled the next morning.
- (2) During hauling, salmon were fin clipped to record direction of entry on capture (in effect after 1958). Blood samples, if requested, were pro-

vided for independent studies from live fish. Fish were then placed in bins according to mesh size of capture.

- (3) Once hauling was completed, each specimen in a catch, up to 250 fish, was saved for shipment to the laboratory. These were selected according to two separate size groups: 125 fish were taken from the large meshes (4½-inch and 5¼-inch), and 125 fish from the small meshes (2½-inch and 3¼-inch). If the total catch in a mesh size grouping exceeded 125, fish were selected randomly in proportion to the catch by mesh size within that grouping. If the total catch in a mesh size grouping was less than 125, then all fish were saved. Selection of whole fish was not influenced by their condition, except that fish without heads or tails were not retained for the laboratory. An identifying tag was placed on fish saved.
- (4) Length from tip of snout to fork of tail was read from a measuring board and recorded, and a scale sample was taken from each fish. Starting in 1960, maturity and sex were also recorded for those fish not sent to the laboratory.
- (5) Fish kept for the laboratory were immediately placed on sharp freezing plates, glazed and put

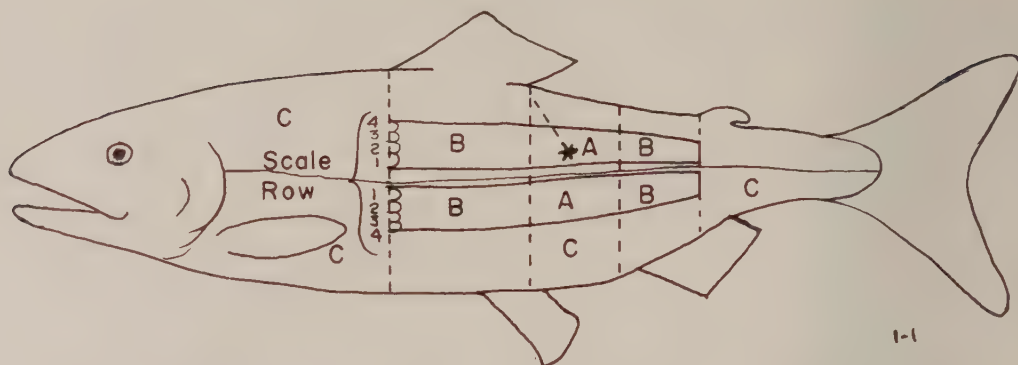


FIGURE 1. Scale sampling code used by agencies of the International North Pacific Fisheries Commission.

Note. The asterisk denotes the preferred scale, which can be found by following the diagonal scale line from the posterior edge of the dorsal fin to the second scale row above the lateral line. "A" is the preferred area if the preferred scale is missing. "B" is the second choice area if scales in area "A" are missing. "C" areas are all other scales. Scales may be taken from either side of the fish but the left side is preferred.

in plastic bags the next day for later transport to Seattle.

Procedures differed somewhat on Japanese research vessels, but gillnetting operations and handling of whole fish sent to the Bureau of Commercial Fisheries Biological Laboratory, Seattle, Washington, were much the same as on United States research vessels. Whole fish also were collected from predesignated areas and times aboard vessels of Japanese commercial fleets. Here, salmon were tagged with an identification number, frozen, bagged and boxed for eventual shipment to Seattle. Data on fleet name, and on area, date and mesh size of capture accompanied each specimen.

Body weights of fresh fish are limited in this study to 335 records collected by the authors with a spring scale aboard a United States research vessel in 1961. The resulting relationship to weights taken in the laboratory is applied to the years 1956 through 1960.

LABORATORY PROCEDURES

Laboratory procedures for data pertinent to this study likewise changed little from 1956 through 1960. These were as follows:

- (1) *Body weight*—frozen fish, identified by the tags affixed at capture, were thawed approximately five minutes in warm water (70°F. to 80°F.) to remove the glaze. They were next placed on a table to let excess water drip off, then weighed to the nearest dekagram on a calibrated spring scale.
- (2) *Length*—various lengths on thawed fish were taken to the closest millimeter on a calibrated

drum-type machine (Thompson and Hart MS).

- (3) *Sex and gonad weight*—visual examination of gonads determined sex. Large or maturing gonads were weighed to the nearest gram on a calibrated beam scale; small or immature gonads, to the nearest 0.1 gram.
- (4) *Age*—the preferred scale, or one from other designated areas of the body if that scale was missing (see Fig. 1), was removed for later definition of freshwater and ocean ages and for recording of certain other data.

Only those fish processed through the laboratory have been considered here. Of the various lengths recorded in the laboratory, we used only the distance in millimeters from tip of snout to fork of tail. To examine effects of net selectivity, we also used fork lengths, as recorded at sea on United States research vessels, of some of the same fish. Winters at sea before capture were the only scale data utilized. Published studies by Godfrey (1961) and by Ishida *et al.* (1961) provided criteria for separating immature and maturing fish. In the present investigation, gonad weights above 2 and 15 grams were taken to represent maturing males and females, respectively.

EFFECTS OF AREA OF ORIGIN

The first problem was to find if sockeye salmon stocks other than the Western Alaskan were represented in the data. If so, and if Western Alaskan fish differed from them in average size, then pooling all data without regard to origin could bias estimates of growth for Western Alaskan fish. Therefore, it was

ecessary to test the hypothesis of no difference in average size between origins. This required means classifying fish in high seas catches by origin. When acceptable criteria of classification, rejection of the null hypothesis would then require additional means of identifying individual Western Alaskan fish in order to estimate their growth. Of course, acceptance would imply this particular source of variation should not be considered further.

Fukuhara *et al.* (1962) developed a discriminant function that classifies sockeye salmon taken on the high seas as "Western Alaskan" or "Asian". Several length-independent characters from mature fish of known continental origin were combined into a single function. A value of this function was computed for each fish used to define continental morphotypes. From overlap in the two resulting normal curves, risks of misclassifying Asian fish as Western Alaskan, and vice versa, were computed for each year of sampling. The midpoint between means was taken as a critical point for classifying individuals captured on the high seas.

That study demonstrated intermingling of continental stocks. Percentage estimates of Western Alaskan fish in high seas catches were derived by classifying individuals from the critical point of the discriminator. For the years 1956 through 1960, a later study (Landrum and Dark, MS) showed that risks of misclassification for Asian fish ranged from 24 percent to 37 percent, with an average of 29 percent; risks of misclassification for Western Alaskan fish varied from 18 percent to 24 percent, with an average of 22 percent.

On the average, then, 29 individuals from a catch of 100 would be classified as Western Alaskan if all 100 were actually from Asia; 22 from 100 would be classified as Asian if all 100 were in fact from Western Alaska. The bias in percentage estimates of intermingling is greatest in the case just given—when all individuals in a catch are from one continent. This bias vanishes when approximately one-half of the fish in a catch are from each continent. To account for incomplete separation of original morphotypes, a correction was applied (in the studies cited) to the initial classification of a high seas catch in order to estimate its true continental composition. Had separation of morphotypes been complete, of course, the risk of misclassifying an individual taken on the high seas could then be stated as 0.

Four aspects of the studies cited are of particular interest here: (1) segregation of fish by continental

origin is based on a set of characters which are independent of length, (2) risks of misclassifying individual fish are unknown, (3) average risks of misclassification are 29 and 22 percent for Asian and Western Alaskan fish, respectively, and (4) misclassified individuals increasingly compensate as intermingling increases—until the error vanishes when approximately one-half of the fish in a catch are from each continent.

In testing the hypothesis of no difference in mean size between origins, it was of first importance to group data so as to remove extraneous sources of variation. Sex, maturity and winters at sea before capture were obvious sources. Since discrimination between continents was independent of length, the effects of mesh selectivity should not influence this particular analysis. From cited classifications of individuals taken on the high seas, the present test of size by origin could be performed by using either: (1) all fish in individual catches of "pure" continental origin which were made at the same time, or (2) those fish in individual catches made at the same time but representing nearly equal mixtures of fish from both continents. Of course, combinations of these two alternatives might also be used. To be avoided, however, in view of unknown risks of misclassification for individuals, were those catches which were neither "pure" nor "nearly equal mixtures". Finally, possible bias in the outcome from any (environmental) effects on average size due to area of capture would be more likely in "pure" catches; these are (almost) by definition made in different areas, whereas catches of "nearly equal mixtures" are by definition from the same areas. Were effects of area of capture significant, to admit them as random variation seemed more reasonable than to risk their confounding the required test of differences in average size between areas of origin.

TEST OF THE NULL HYPOTHESIS

Those individuals taken between 160°30'W. longitude and 160°30'E. longitude, and which had all pertinent data on record, were classified by winters at sea before capture, and by sex, maturity, "origin" and 10-day periods, starting in May in each year from 1956 through 1960. Classification by "origin" was according to whether the value computed for an individual fish fell below or above the critical point ($Y_0=69.308$) of the discriminant function (Fukuhara *et al.*, 1962). Figure 2 shows the general area of sampling and, for later reference, its division into 1° rectangles of latitude and longitude. The 10-day periods are defined below:



This definition of 10-day periods was arbitrary. As it turned out, the numbers of maturing 1-winter and immature 3-winter fish taken in all periods, and of all ocean ages taken in periods 1 and 2, were too small to warrant analysis here.

Next, study of cruise patterns of the High Sea Research Unit and of results of the classificatory studies by Fukuhara *et al.* (1962) and Landrum and Dark (MS) showed that few catches of "pure" continental origin were made within a 10-day period. To use data from different 10-day periods would obviously introduce effects of seasonal growth into the test of size by origin. Along with possible effects of area of capture (see page 5), these considerations led us to adopt a criterion of "nearly equal mixtures." Accordingly, only those samples having from 40 percent through 60 percent Western Alaskan individuals were used to test for differences in size by origin. Where representation from a dominant area was desirable from the standpoint of large sample size or to ensure balance between the several life history groups, catches were used from only that area in order to satisfy the 40-60 percent criterion.

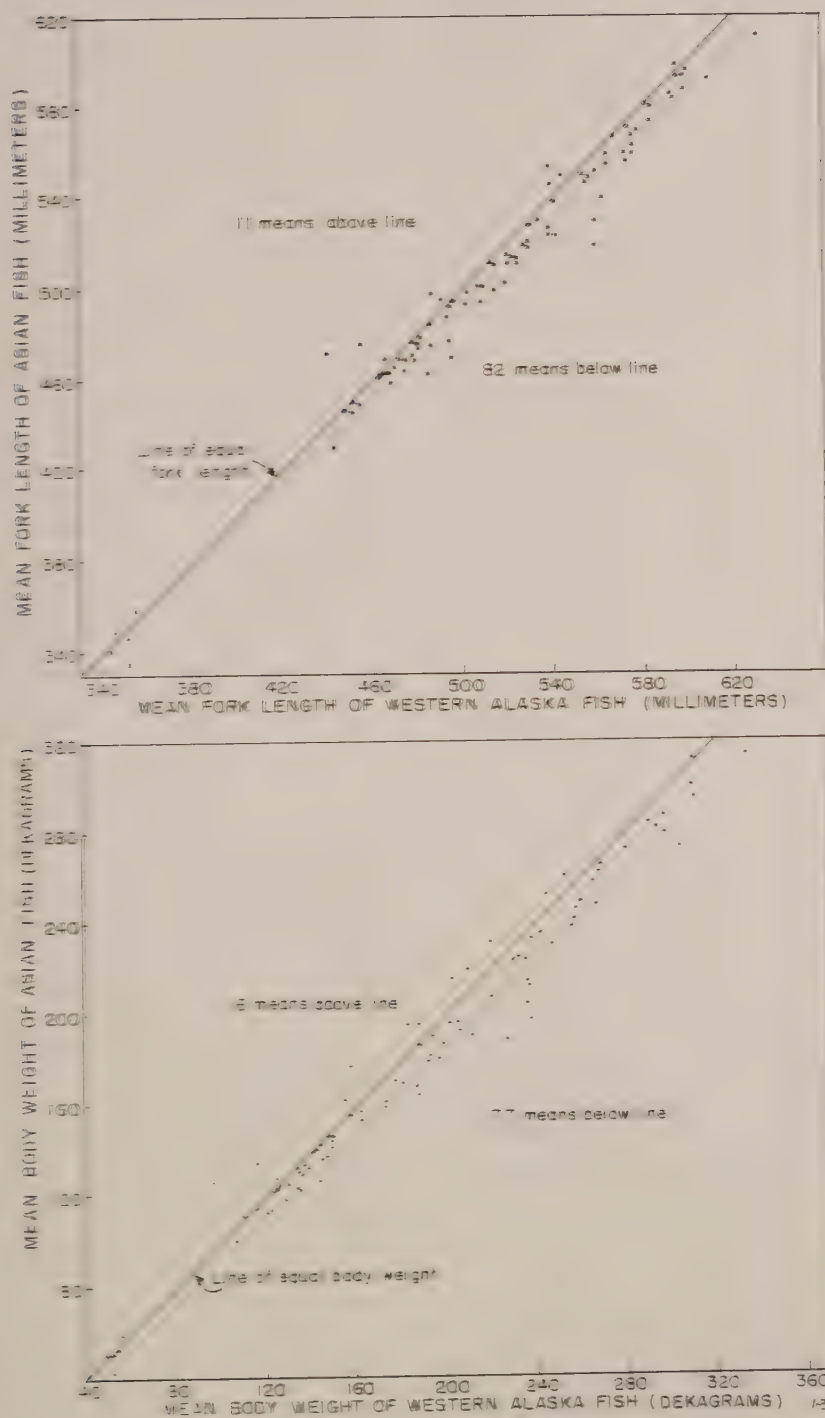


FIGURE 1. Mean length and weight of Asian and Western Alaskan sockeye salmon, relative to line of 1:1

(continued)

TABLE 2. Test of the hypothesis of no difference in mean fork length between Asian and Western Alaskan sockeye salmon.

Test group number	Life history group ¹	Sample size	Rejection level in i^{th} test (p_i)	$\ln p_i$
1	M-I-2	46	.12	-2.207
2	M-M-2	77	.09	-2.408
3	F-M-2	32	.70	-0.357
4	M-I-2	195	.04	-3.219
5	F-I-2	83	.41	-0.916
6	M-M-3	124	.32	-1.171
7	F-M-3	448	.01	-4.605
8	M-I-1	93	.06	-2.813
9	F-I-1	107	.68	-0.386
10	M-I-2	118	.14	-1.966
11	F-I-2	164	.21	-1.561
12	M-M-3	162	.33	-1.109
13	F-M-3	456	.01	-4.605
14	M-M-2	212	.87	-0.139
15	F-M-2	549	.01	-4.605
16	M-I-2	363	.13	-2.040
17	F-I-2	447	.01	-4.605
18	M-M-3	106	.10	-2.303
19	F-M-3	123	.36	-1.022
20	M-M-2	207	.01	-4.605
21	F-M-2	223	.24	-1.427
22	M-I-2	562	.17	-1.772
23	F-I-2	519	.06	-2.813
24	M-M-3	185	.19	-1.661
25	F-M-3	656	.02	-3.912
Total		6,257		-58.177

$$C = -2 \sum_{i=1}^s \ln p_i = (-2)(-58.177) = 116.354 \text{ (with 50 degrees of freedom)}$$

$$p < 0.01$$

Explanation: To retain workable probabilities in the test:

$$C = -2 \sum_{i=1}^s \ln p_i \text{ (a chi-square summary of } s \text{ independent tests}$$

of the same null hypothesis, where p is the observed rejection level in each test and C has $2s$ degrees of freedom), the value 0.01 was substituted for highly significant differences in the i^{th} test—when $\ln p_i$ was zero to two decimals. C was significant at the 99 percent level.

¹ M—male, F—female; I—immature, M—maturing; 1, 2, 3—number of winters at sea before capture.

The 40–60 percent criterion rejected certain large catches of maturing fish taken north of the Aleutian Islands in June, particularly in 1956 and 1960. That these fish were on the spawning migration to Bristol Bay, Alaska, has been clearly demonstrated by the classification studies by Fukuhara *et al.* (1962) and Landrum and Dark (MS), and by independent tagging experiments (Hartt, 1962). Many individuals so excluded from the test of size by origin could con-

tribute, of course, to final estimates of growth.

Individual tests on data retained by the 40–percent criterion then took the form of separate two-way analyses of variance with disproportionate subclass number (Snedecor, 1956). Each analysis represents a different combination of one or more of these factors: sex, maturity, winters at sea before capture, or year of capture. Variables of classification are origins and periods. Expected variation from seasonal growth between 10-day periods is hence removed from comparisons of size by origin. Variability due to area of capture is retained as sampling error (see also the section entitled “Effects of area and year of capture”).

In Figure 3, the positions of means relative to the line of 1:1 correspondence reveal the tendency of Western Alaskan fish to exceed those from Asia in both length and weight. The 93 points in each portion of Figure 3 arise from the fact that two or more periods contributed to each of 25 individual analyses of variance. Of these 93 points, 82 fall below the line of equal length; 77 lie below the line of equal weight. Finally, combined results from the 25 independent tests (using the less variable length data) of the same null hypothesis into the summary of Table 2 show length differences associated with area of origin to be highly significant.

Therefore, pooling all of the high seas data would render estimates of average size too low for Western Alaskan fish. The remaining problem was how to select individuals from Western Alaska.

CRITERIA FOR SELECTING WESTERN ALASKAN FISH

Data from all areas were originally combined. A breakdown by 1° rectangles of latitude and longitude (see Fig. 2) was next imposed on these data and each resulting tabulation was treated as a sample. Given average risks of misclassification of 29 and 22 percent for Asian and Western Alaskan fish, respectively (Landrum and Dark, MS), and again recalling that risks of misclassification were unknown for individuals, the following three criteria were then adopted for selecting Western Alaskan individuals from available samples: (1) reject all samples containing fewer than 50 percent “Western Alaskan” fish, (2) use only individuals falling on the “Western Alaskan” side of the critical point of the discriminator from those samples containing from 50 percent through 69 percent “Western Alaskan” fish, and (3) use all individuals from samples containing over 69 percent “Western Alaskan” fish. An incidental rule was to reject all remaining samples with less than three fish.

After criterion (1) was applied to all available samples, the percentages of Western Alaskan fish in remaining samples were made the basis for applying criteria (2) and (3). Weighted mean fork lengths and body weights of fish from both continents were pooled for samples to which criterion (3) applied. The resulting tabulation showed the tendency, mentioned earlier for means of test groups in Figure 3, for Western Alaskan fish to be larger than Asian fish.

It is important to distinguish once more between the higher 40–60 percent criterion, adopted to test for size differences by origin, and the three criteria just mentioned. The latter three selected Western Alaskan individuals from the available samples, once Western Alaskan fish had been found to be larger than Asian fish. When these three criteria were applied—criterion (1) to all samples, criteria (2) and (3) to the samples remaining after application of criterion (1)—22 individuals remained. At least 85 percent of these in each of the four age-maturity combinations had T values in the “Western Alaskan” region of the original discriminator (Fukuhara *et al.*, 1962).

In view of the meaning and magnitudes of average

risks of misclassification, the three criteria for selecting Western Alaskan fish are believed to admit relatively few Asian fish. One qualification, of course, is that the discriminator was derived from maturing fish only (Fukuhara *et al.*, 1962; Landrum and Dark, MS).

CONVERSION OF LABORATORY OBSERVATIONS TO FRESH WEIGHT AND LENGTH

The basis for conversions is introduced here to explain why lengths and weights are not given for fresh fish, and why a weight-length relationship is not needed.

Weights of 335 fresh fish were taken in 1961 (see “Collection and processing of specimens”), but no weights for fresh fish were on hand for the years 1956 through 1960. Lengths were available from most fresh fish taken by United States research vessels and sent to the laboratory as frozen fish. United States research vessels caught 88 percent of the 8,512 individuals employed in the growth analysis, although as high as 41 percent (in 1956) were from Japanese commercial fleets in individual years. Since growth is more realistically expressed on a fresh basis, weight

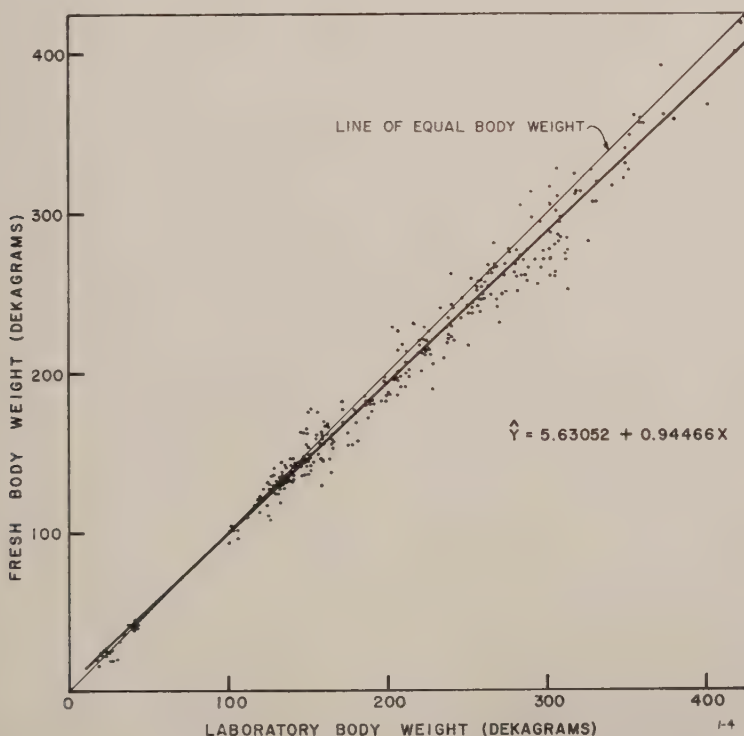


FIGURE 4. Relationship between weights of 335 fresh and partially thawed sockeye salmon collected in 1961.

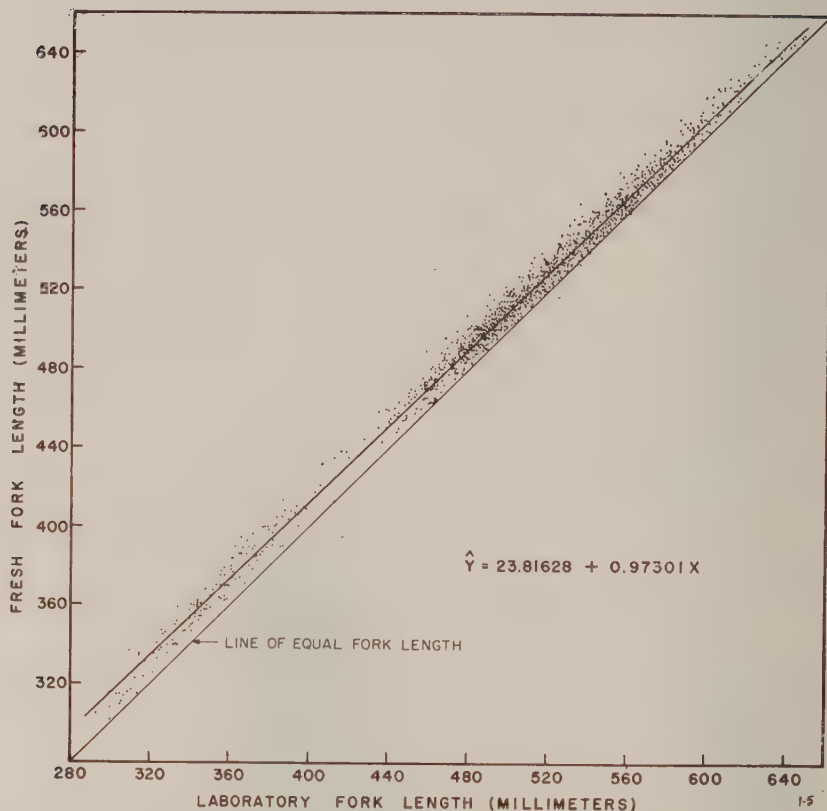


FIGURE 5. Relationship between fork lengths of 1,382 fresh and thawed sockeye salmon collected each year (except 1958) from 1956 through 1960.

records from the laboratory for the years 1956 through 1960 were converted on the basis of and were dependent on the 335 records taken at sea in 1961. The remaining question was whether to use length data taken at sea or in the laboratory.

In comparing 1,484 length records taken at sea with laboratory records from the same fish, 102 laboratory measurements (or 7%) were found to be larger. That fish shrink during freezing is common knowledge. Moreover, accuracy is harder to attain at sea than in the laboratory. Therefore, these 102 fish were discarded from analysis of the effects of mesh selectivity, details of which are given in the next section.

To the extent the above comparison of records is representative, laboratory measurements on thawed fish are likely more accurate than shipboard measurements on fresh fish in the whole body of data. A similar problem in accuracy was noted in connection with tagging experiments, where greater lengths at tagging than at recovery are commonly discarded. In the present study, it seemed reasonable to proceed

with laboratory records, then to convert only average values to a fresh basis as needed near the end of the study. Moreover, the same 1,382 observations were used to examine effects of mesh selection should determine quite precisely the length relationship between fresh and thawed fish. Of course, a different procedure would have been employed had weight and length observations taken at sea been available for all specimens collected from 1956 through 1960.

Figures 4 and 5 show regression lines and equations for converting mean weights and lengths to a fresh basis. Figure 4 indicates that weights of partially thawed fish were greater on the average than weights of the same fish when fresh. Changes in composition of flesh during freezing permit water uptake when fish are immersed in warm water to remove glaze; in addition, water intake through the gut may slightly increase the weight.¹

¹ Personal communication with Richard Nelson of the Bureau of Commercial Fisheries Technological Laboratory, Seattle, Washington.

nally, separate treatment of weight and length adds the need for a weight-length relationship. It is possible that weight gain and length loss could substantially alter the weight-length relationship that existed in the fresh fish.

EFFECTS OF SIZE SELECTIVITY BY GILLNETS

Size selectivity by gillnets is clearly a potential source of error in estimating growth. For instance, even mesh size may select large fish from a life history group early in the season, small ones later. The resulting estimate of seasonal growth would then be too low. Other effects are conceivable on both seasonal and long-term growth rates. In present data, moreover, changes from year to year in proportions of each mesh size fished (see Table 1) tend to complicate effects of selection for size.

Readers interested in the theory of mesh selection are referred to papers by Olsen (1959) or McCombie and Fry (1960); its initial exposition in English by Holt (1957), while excellent, is perhaps not readily available. Recounted here is background information sufficient to clarify later analysis.

The chance of a fish being captured when swimming into a gillnet depends strongly on its girth relative to the mesh opening. Over a range of length (and therefore, of girth), Holt (1957) was able to estimate selection curves, normal in shape, for each mesh size used in a graduated series of sizes. A selection curve shows the risk of retention at any length relative to that at the mean selection length; the latter is the length at which retention is most likely for a given mesh size. By assuming no particular shape for a selection curve in advance of its estimation from catch data by fish length and mesh size, Olsen (1959) applied a more general model to Newfoundland herring. McCombie and Fry (1960) cited these and earlier Russian studies, and examined directly the ratio of fish girth to mesh perimeter. The latter authors then found total catch, when pooled from a series of graduated mesh sizes fishing together with equal effort and covering the length range of whitefish (*Coregonus clupeaformis*) locally available, was a representative sample of length. Still other workers have applied the basic ideas to various species.

Peterson (MS) has followed this theory in estimating sockeye, chum and pink salmon, selection curves for 2½-inch, 3¼-inch, 4½-inch and 5¼-inch meshes. Mesh sizes are average measured distances between opposite knots of multifilament nylon stretched taut.

United States research vessels employed these four mesh sizes from 1956 through 1960, but in varying amounts (see Table 1); recall that these vessels took 88 percent of the 8,512 fish employed in the growth analysis. Peterson (MS) then, used lengths of the same fish, when fresh, from most of the same catches to construct his mesh selection curves for sockeye salmon. He summed data separately within "spring" (May-June) and "summer" (July-August) seasons and over all life history groups within a season. A breakdown of catches by date, winters at sea, sex and maturity would have left too few fish to estimate curves with confidence.

Now the basic reason for estimating selection curves is to relate the size composition of fish in the catch to the sizes of fish in the water. The theory requires that each mesh size in a graduated series be fished with equal effort. Since United States research vessels fished differing amounts of each mesh size in various years (see Table 1), Peterson (MS) had to place catches on a per-unit-effort basis before constructing his curves. Unfortunately, we have no data adequate for testing the assumption that catch varies directly with amount of gear. That nets very rarely reached "saturation" levels in the present study is perhaps the only observation to be made on this point.

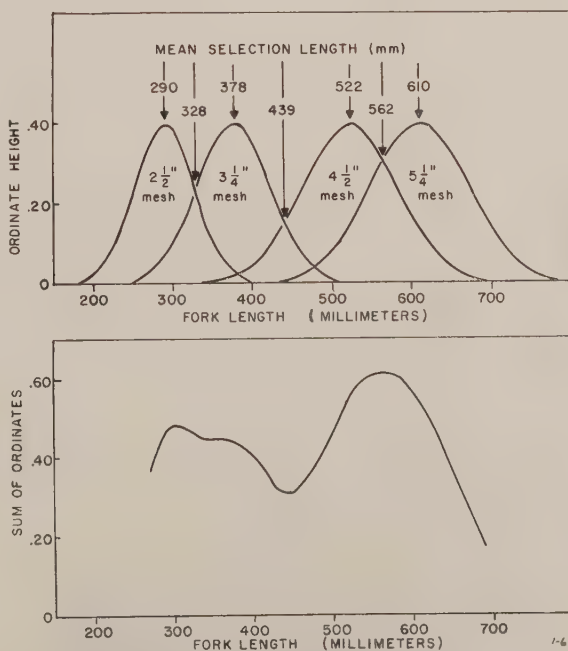


FIGURE 6. Individual and composite mesh selection curves for sockeye salmon.

TABLE 3. Ordinates of individual and composite selection curves for sockeye salmon, as constructed from average of yearly values given by Peterson (MS).

Fork length class (mm.)	Ordinates by mesh size				Sum of ordinates for composite curve
	2½"	3¼"	4½"	5¼"	
270	.342	.025			.367
280	.384	.040			.424
290	.399	.063			.462
300	.385	.094			.479
310	.345	.133	.000		.478
320	.287	.180	.001		.468
330	.220	.232	.001		.453
340	.156	.285	.002		.443
350	.104	.333	.005		.442
360	.063	.371	.008		.442
370	.036	.394	.013		.443
380	.019	.398	.020	.000	.437
390	.009	.385	.030	.001	.425
400	.004	.354	.044	.001	.403
410	.002	.310	.062	.002	.376
420	.001	.259	.085	.003	.348
430	.000	.206	.114	.006	.326
440		.156	.148	.009	.315
450		.113	.185	.014	.312
460		.078	.225	.021	.324
470		.051	.266	.031	.348
480		.032	.306	.044	.382
490		.019	.341	.061	.421
500		.011	.371	.083	.465
510		.006	.390	.109	.505
520		.003	.399	.139	.541
530		.002	.396	.174	.572
540		.001	.381	.211	.593
550		.000	.357	.252	.609
560			.324	.290	.614
570			.285	.325	.610
580			.244	.356	.600
590			.204	.379	.583
600			.165	.394	.559
610			.129	.399	.528
620			.099	.393	.492
630			.073	.378	.451
640			.052	.354	.406
650			.036	.323	.359
660			.025	.286	.311
670			.016	.245	.261
680			.010	.208	.218
690			.006	.171	.177

Mean selection lengths and standard deviations of sockeye salmon curves for a given mesh size differed little between "spring" and "summer" seasons or between the years 1956 through 1960 (Peterson, MS). Therefore, we constructed here a single curve for each mesh size. In the top of Figure 6, ordinate heights at any length show the risk of retention rela-

tive to that at the mean selection length (i.e., t mode), at which retention is most likely. The 2-inch mesh is assumed to retain available 290-mm fish with the same efficiency that the 3¼-inch mesh retains available 378-mm. fish. This assumption applies generally to any two adjacent mesh sizes. Also, those just mentioned retain 328-mm. fish with equal efficiency, and so forth for other lengths at intersection. Summing ordinate heights (see Table 3) for a given length class over all meshes (after McCombie and Fry, 1960) yields the composite selection curve in the bottom of Figure 6. The range of this curve corresponds to the length range of thawed fish in all life history groups.

If the theory of mesh selectivity is valid, then, any catches may be put on the basis of equal effort before estimating selection curves under that theory. The present data may be examined for effects of mesh selectivity by gillnets. Our procedure is: (1) to estimate the length composition of fish in the water from the composite mesh selection curve in Figure 6 and from catches based on equal effort by mesh size and then, (2) to compare this expected composition with the length composition taken by the number of shackles of each mesh size actually fished. Rejecting the hypothesis of no difference in length distributions should then provide evidence of selectivity.

SELECTION OF DATA

Table 4 identifies 28 test groups selected from samples with 50 percent or more "Western Alaskan" fish. These represent all sampled life history groups and years of sampling (except 1958); therefore, they also represent all fish lengths and allocations of mesh size by effort for U. S. research vessels (again, see Table 1). Single large catches were first chosen from these 28 test groups in Table 4. Next, catches from the same area were combined for different dates within a 10-day period. Finally, catches from different areas were pooled within a 10-day period.

Of course, all catches represented in any one test group of Table 4 are from the same composition of mesh sizes. The reason for combining dates or areas rather than choosing only the more desirable single large catches, was to ensure balance between large samples and representation of all life history groups. While the effects of mesh size, not area of origin, are of concern here, recall none of these samples contains less than 50 percent "Western Alaskan" fish (see "Effects of area of origin"). Moreover, 19 of the 28 test groups in Table 4 were from samples containing over 69 percent "Western Alaskan" individuals.

TABLE 4. Identification of test groups selected for testing the hypothesis of no selectivity for size in data used to estimate growth.

Test group number	Life history group ¹	Year	Month and day	Period (see p. 6)	Area (see Fig. 2)	N	No. of shackles fished by mesh size			
							2½"	3¼"	4½"	5¼"
1	M-I-1	1957	8/12	11	1293	15	4	4	10	5
2	"	1957	8/11, 17, 18	11	1293	39	4	4	11	5
3	"	1959	7/13	8	1210	11	4	4	24	4
4	F-I-1	1957	8/12	11	1293	8	4	4	10	5
5	"	1957	8/11, 17, 18	11	1293	30	4	4	11	5
6	"	1957	8/9	11	1017	6	4	4	12	4
7	"	1960	7/20, 21, 23, 28	9	1119, 1205	38	4	4	24	4
8	M-I-2	1956	8/25	12	1122	46	3	3	6	6
9	"	1957	8/19, 23	12	1191	87	4	4	11	5
10	"	1960	8/14, 17, 18	11	1114	90	4	4	24	4
11	"	1960	8/20	12	1015	28	4	4	24	4
12	F-I-2	1956	8/25	12	1122	39	3	3	6	6
13	"	1957	8/19, 23	12	1191	54	4	4	11	5
14	"	1959	8/6	10	1017	46	4	4	24	4
15	"	1960	8/14, 17, 18	11	1114	66	4	4	24	4
16	M-M-2	1956	6/20	6	1542	73	3	3	6	6
17	"	1957	6/21, 22	6	1544	31	3	3	9	3
18	"	1959	6/12, 14, 15	5	1200	82	4	4	24	4
19	"	1959	6/23	6	1450	26	4	4	24	4
20	"	1960	6/20	6	1451	52	4	4	24	4
21	F-M-2	1956	6/20	6	1542	60	3	3	6	6
22	"	1959	6/12, 14, 15	5	1200	43	4	4	24	4
23	"	1959	6/26	6	1532	61	4	4	24	4
24	"	1960	6/25	6	1280	57	4	4	24	4
25	M-M-3	1957	6/18, 19	5	1542	15	3	3	9	3
26	"	1957	6/15, 17	5	1537, 1539	40	4	4	12	4
27	F-M-3	1957	6/18, 19	5	1542	67	3	3	9	3
28	"	1957	6/15, 17	5	1537, 1539	172	4	4	12	4
Total						1,382				

¹ See note 1, Table 2.

inally, only individuals classified as "Western Alaskan" were included in the nine remaining test groups of Table 4.

Fork lengths of fresh fish were used in the analysis to follow. Of 1,568 individuals originally selected for the analysis, fork lengths recorded at sea were smaller than those recorded in the laboratory for 302 fish; the latter were discarded (see "Conversion of laboratory observations to fresh weight and length"). In addition, lengths of fresh fish were not available for 84 specimens from a large catch of June 10, 1956, made north of the Aleutian Islands in area 1542 (see Figure 2). Therefore, only 1,382 of the 1,568 individuals first selected are actually represented in Table 4.

Certain large catches of 1-winter fish taken from area 1200 (see Fig. 2) in 1959, the year of highest catches for that age group, lacked identifying infor-

mation on mesh size of capture. This is reflected in Table 4 by the few entries for 1-winter fish. The average number available for tests on 2-winter and 3-winter fish was 59. The latter seems adequate to avoid a high risk of falsely accepting the null hypothesis of no selectivity for size.

ANALYSIS OF LENGTH FREQUENCIES

Table 5 illustrates calculations performed on each test group of Table 4. Actual catch data by length class and mesh size were first adjusted to unit effort and summed over all meshes. The total adjusted catch in each length class was then divided by the corresponding ordinate of the composite selection curve (see Fig. 6 and Table 3). The latter values, when put on a percentage basis, are estimates of the length composition of fish in the water under the theory of net selectivity. Next, the estimated percentage in each length class was multiplied by total

TABLE 5. Chi-square calculations for test group 9 (Table 4), illustrating derivation of length frequencies expected under the hypothesis of no selectivity for size. Small expected frequencies are summed to exceed 5.0 in the chi-square test.

Midpoint of 10 mm. fresh fork length class	Actual catch by mesh size					Catch by mesh adjusted to common effort of one shackle ¹				Ordinate of composite selection curve (Fig. 6 and Table 3)	Comparison of observed and expected values										
					Total observed catch				Total adjusted catch												
	2½"	3¼"	4½"	5¼"		3¼"	4½"	5¼"			A ²	B ³	Expected	(O-E)	(O-E) ²	(O-E) ² /E					
460	—	—	1	—	1	—	0.091	—	0.091	.324	0.281	1.3	1.13	5.22	-2.22	4.93	0.9				
470	—	1	1	—	2	.250	0.091	—	0.341	.348	0.980	4.7	4.09								
480	—	1	3	2	6	.250	0.273	.400	0.923	.382	2.416	11.6	10.09	5.22	-4.09	16.73	1.6				
490	—	—	11	—	11	—	1.000	—	1.000	.421	2.375	11.4	9.92								
500	—	2	12	—	14	.500	1.091	—	1.591	.465	3.422	16.4	14.27	5.22	-0.27	0.07	0.0				
510	—	—	10	2	12	—	0.909	.400	1.309	.505	2.592	12.4	10.79								
520	—	2	9	3	14	.500	0.818	.600	1.918	.541	3.545	17.0	14.79	5.22	-0.79	0.62	0.0				
530	—	—	7	1	8	—	0.636	.200	0.836	.572	1.462	7.0	6.09								
540	—	—	6	1	7	—	0.546	.200	0.746	.593	1.258	6.0	5.22	5.22	1.78	3.17	0.6				
550	—	1	3	2	6	.250	0.273	.400	0.923	.609	1.516	7.2	6.26								
560	—	—	4	1	5	—	0.364	.200	0.564	.614	0.918	4.4	3.83	10.70	1.30	1.69	0.1				
570	—	—	1	—	1	—	0.091	—	0.091	.610	0.149	0.7	0.61								
											20.914							4.2			
Total catch	0	7	68	12	87									87.09							
Effort ⁴	4	4	11	5																	
											chi-square .95(8)=15.50										

chi-square .95(8)=15.50

¹ Actual catch by length in each mesh, divided by effort for each mesh.² Total adjusted catches divided by corresponding ordinate of composite selection curve.³ Expected percentage length composition; each value in column "A" is divided by column "A" total.⁴ Total effort in 50-fathom shackles.

actual catch to allocate the latter into numbers expected under the null hypothesis. Finally, the chi-square analysis in Table 5 shows that expected catches in each length class and in the whole distribution did not differ from actual catches for test group 9 of Table 4.

Table 6 summarizes results of similar calculations for all 28 test groups of Table 4. Only the immature 2-winter females of test group 15 gave a probability value (0.01) small enough to be significant. The summary result is far from significant (p is 0.85).

Since the composite mesh selection curve in Figure 6 shows that fish of some lengths—particularly in the range from 400 mm. to 500 mm.—are much less vulnerable than fish of other lengths, the outcome of Table 6 may at first seem surprising. Two items may be noted in this regard. First, McCombie and Fry (1960) showed for another species (*Coregonus clupeaformis*) that the total catch from all mesh sizes, provided those sizes were fished together and covered the length range of fish available, was a representative sample of length. Secondly, and perhaps a more important factor here, is the fact that a single

mesh size captured most of the fish taken from single life history group (see Table 7). The length range covered by the composite selection curve (Figure 6) is much greater than the length range of an individual life history group. That Table 6 gave a non-significant result, therefore, is perhaps not entirely surprising.

We believe some size selectivity must occur in the data. The outcome of Table 6 would likely have been different had several life history groups been combined together. To the extent that the existing theory of mesh selection and the method used by Peterson (MS) to develop selection curves for sockeye salmon are valid, however, we conclude that size selectivity by gillnets should not seriously distort the composite picture of growth, which is the objective of the present study.

EFFECTS OF AREA AND YEAR OF CAPTURE

This picture must be assembled from certain groupings of data dictated by actual coverage in space and time; to estimate growth was not the primary purpose.

TABLE 6. Test of the hypothesis that gillnets, as fished, caused no selectivity for size in data used to estimate growth.

Test group number	Life history group ¹	Rejection level in i^{th} test (p_i)	$\ln p_i$
1	M-I-1	0.43	-0.84
2	"	0.98	-0.02
3	"	0.89	-0.12
4	F-I-1	0.97	-0.03
5	"	1.00	0
6	"	0.96	-0.04
7	"	1.00	0
8	M-I-2	0.80	-0.22
9	"	0.83	-0.19
10	"	0.06	-2.81
11	"	0.15	-1.90
12	F-I-2	0.89	-0.12
13	"	0.42	-0.87
14	"	0.96	-0.04
15	"	0.01	-4.61
16	M-M-2	0.99	-0.01
17	"	0.96	-0.04
18	"	0.15	-1.90
19	"	0.68	-0.39
20	"	0.14	-1.97
21	F-M-2	0.90	-0.10
22	"	0.29	-1.24
23	"	0.70	-0.36
24	"	0.31	-1.17
25	M-M-3	0.33	-1.11
26	"	0.19	-1.66
27	F-M-3	0.92	-0.08
28	"	0.44	-0.82
Total			-22.66

$$\chi^2 = -2 \sum_{i=1}^8 \ln p_i = (-2)(-22.66) = 45.32 \quad (\text{with } 2s = 56)$$

degrees of freedom)

0.85

See note 1, Table 2.

TABLE 7. Summary of United States research vessel catches of sockeye salmon, 1956 through 1960, by life history group and mesh size.

Life history group ¹	Total fish	Percentage taken in each mesh			
		2½"	3½"	4½"	5½"
M-I-1	940	20	74	6	0
F-I-1	796	28	67	4	1
M-I-2	3,079	0	6	88	6
F-I-2	2,766	1	11	86	2
M-M-2	3,113	1	2	80	17
F-M-2	2,549	0	1	88	11
M-M-3	776	2	4	60	34
F-M-3	1,627	0	2	76	22

See note 1, Table 2.

of sampling. Study of the amount of data available for each life history group demonstrated the need for combinations by time and area.

Variability in average size between areas of capture must be admitted even under a sampling survey designed for estimating growth. The fact that a life history group is broadly distributed means its members could be growing in different environments; these, in turn, could modify average size from area to area. The question is then how to weight these averages for proper representation of the entire life history group of Western Alaskan sockeye salmon. Appropriate weighting factors, however, would require a precise knowledge of relative abundance by area which is beyond the scope of current sampling effort by research vessels. When sampling is not designed for estimating growth, the alternative is to combine data from the different areas without weighting.

Area comparisons in Table 8 are, nevertheless, interesting. Of 30 individual F or t tests (F for three or more areas, t for two) on fork length of immatures, only two gave probability values below 0.05—a result close to chance expectation. On the other hand, 15 of the 45 test results for maturing fish were significant at the 95 percent level. Study of significant area differences in Table 8, of corresponding mean lengths, and of the map in Figure 2, revealed no definite geographic pattern. Maturing 2-winter and 3-winter sockeye salmon do tend to be slightly larger if sampled towards Bristol Bay, Alaska, than if sampled to the westward in the same 10-day period.

Results in Table 8 suggest that immatures, relative to maturing fish, are too young or small to grow differentially in the various physical regimes (or areas) encountered during the first year or two of life at sea. On the other hand, maturing Western Alaskan sockeye salmon evidently encounter regimes (or areas) which are in fact different; these fish are apparently now old or large enough to express inherent capacity for differential growth. More than anything, perhaps, the results of Table 8 demonstrate a need for basic inquiry into the biology of salmon growth at sea. Of particular importance is an understanding of the mechanisms governing interactions between growth, maturation and environment.

Data from different areas of capture, then, will be combined because of inexact knowledge of relative abundance in each. Also, to regard the years 1956 through 1960 as a random sample of environment-response combinations is consistent with providing a composite picture of growth from limited sampling.

TABLE 8. Sources of data and results of comparisons of average fork length by area.

Life history group ¹	Year	Period (see p. 6)	Test number	Area ² (see Fig. 2)	Sample size	Distance apart ³	Significance .95 level
<i>M-I -1</i>	1956	12	1	1117	18	Near	—
				1122	11		
	1959	8	2	1210	7	Near	—
				1276	22		
				1380	23		
				1114	36		
	1960	9	4	1200	105	Far	—
				1119	10		
1205				29			
1117				9			
<i>F-I -1</i>	1957	12	5	1017	23	Far	—
				1114	42		
	1959	9	6	1200	46	Near	—
				1117	9		
<i>M-I -2</i>	1956	12	7	1122	52	Near	—
				1007	10		
	1957	10	8	1017	37	Mixed	—
				1112	30		
				1017	23		
				1293	24		
				1017	27		
				1112	31		
				1201	11		
				1007	20		
		12	11	t-10	69	Far	—
				1007	20		
				t-10	69		
				1191	89		
				1007	20		
				1191	89		
				1205	9		
				1690	11		
	1959	7	14	1210	20	Near	—
				1276	22		
				1380	21		
				1020	19		
		8	15	1108	17	Far	—
				1110	38		
				1189	24		
				1294	52		
	1960	6	16	1119	91	Far	—
				1205	30		
1117				20			
1122				48			
1957		10	20	1112	31	Near	—
				1017	26		
		11	21	1293	31	Far	—
				1007	29		
		12	22	1191	55	Near	—
				1017	19		
		12	23	1112	20	Near	—
				t-22	84		
t-23	39						
1117	20						
<i>F-I -2</i>	1956	12	19	1122	48	Near	—
				1117	20		
	1957	10	20	1112	31	Near	—
				1017	26		
		11	21	1293	31	Far	—
				1007	29		
		12	22	1191	55	Near	—
				1017	19		
		12	23	1112	20	Near	—
				t-22	84		
		12	24	t-23	39	Far	—
				1117	20		

Continued . . .

TABLE 8. Continued.

Life history group ¹	Year	Period (see p. 6)	Test number	Area ² (see Fig. 2)	Sample size	Distance apart ³	Significance at .95 level
M-M-2	1959	7	25	1205	13	Far	*
				1302	11		
				1690	8		
		8	26	1276	28	Near	—
				1380	22		
		9	27	1191	11	Far	—
				1200	27		
		10	28	1017	47	Near	—
				1112	25		
	1960	8	29	1110	42	Far	—
				1189	21		
				1294	42		
		9	30	1119	125	Far	—
				1205	35		
	1956	4	31	1187	20	Near	—
				1190	10		
		6	32	1290	26	Far	—
				1542	131		
		3	33	1122	11	Far	—
				1203	28		
		4	34	1117	30	Far	—
				1126	11		
		5	35	1463	19		
				1200	95	Near	—
				1365	19		
				1288	13	Near	—
		6	36	1454	17		
				1532	24		
		6	37	1705	22	Near	—
				1748	12		
		6	38	t-36	54	Far	*
				t-37	34		
		6	39	1369	32	Near	*
				1450	33		
				1536	24		
				1611	32		
	1960	3	40	1020	29	Near	*
				1108	49		
		3	41	1020	29	Far	*
				1294	27		
		3	42	1108	49	Far	*
				1294	27		
		4	43	1116	70	Near	—
				1117	63		
		5	44	1284	63	Near	—
				1285	62		
				1286	84		
				1368	63		
		5	45	1369	46		
				1198	15	Far	—
				1537	21		
				1205	23	Near	*
		6	46	1280	37		

Continued...

TABLE 8. Continued.

Life history group ¹	Year	Period (see p. 6)	Test number	Area ² (see Fig. 2)	Sample size	Distance apart ⁸	Significance .95 level
<i>F-M-2</i>	1955		47	1375	20		
				1444	34		
				1542	49		
				1540	55	Near	—
			48	1609	49		
				t-47	104	Far	—
			49	1451	63		
				t-47	104	Far	—
		8	50	1699	25		
				1107	9	Near	1 *
				1110	14		
	1956	5	51	1187	34	Near	—
				1188	16		
		6	52	1290	59	Far	—
				1542	82		
	1957	5	53	1283	14	Mixed	—
				1537	25		
				1542	18		
				1203	10	Near	—
	1959	3	54	1205	12		
				1200	52	Near	—
		6	56	1365	30		
				1288	33	Near	—
		6	57	1454	15		
				1532	63		
				1369	31	Near	*
				1450	30		
	1959	6	58	1536	32		
				1611	19		
				1705	22	Near	—
				1748	13		
		6	59	t-56	111	Far	*
				t-58	35		
	1960	3	60	1020	27	Near	—
				1108	22		
		4	61	1116	26	Near	—
				1117	17		
		5	62	1284	30	Near	*
				1285	33		
				1286	21		
				1368	76		
		5	63	1369	34		
				1537	10	Near	*
				1611	11		
				1280	59	Near	—
		6	64	1375	49		
				1444	40		
				1542	50		
				1540	29	Near	—
	1960	8	66	1609	34		
				993	17	Far	—
		8	66	1110	26		
				1290	11	Far	*

M-M-3

1956

6

67

1290

11

Far

*

Continued . . .

TABLE 8. Continued.

Life history group ¹	Year	Period (see p. 6)	Test number	Area ² (see Fig. 2)	Sample size	Distance apart ³	Significance at .95 level
F-M-3	1957	5	68	1542	14	Near	*
				1537	30		
				1539	14		
				1542	18		
	1957	6	69	1288	8	Far	*
				1544	19		
				1694	10		
				940	11		
	1958	2	70	1000	22	Far	—
	1957	5	71	1537	109	Near	*
				1539	77		
				1542	74		
				1288	15		
	1957	6	72	1544	33	Far	—
				1694	23		
				1537	10		
				1692	19		
	1958	5	74	1280	9	Near	—
	1959	6	75	1539	23	Far	—
				1369	19		
				1616	16		

Summary of Results.

	Distance	Immature	Mature	Total
Significant	Near	0	9	9
	Mixed	0	0	0
	Far	2	6	8
	Total	2	15	17
Not significant	Near	15	17	32
	Mixed	1	1	2
	Far	12	12	24
	Total	28	30	58
GRAND TOTAL		30	45	75

¹ See note 1, Table 2.² Letter "t" followed by numerals indicates test number of pooled areas.³ Distance apart in latitude or longitude: *Near*—approximately 1-5 degrees apart; *Far*—6 degrees or more; *Mixed*—Near and Far areas tested together.

* Significant.

in this view the data for the several years would be grouped within 10-day periods to approximate seasonal and long-term growth of Western Alaskan sockeye salmon.

Here again, substantial differences in average size between years are of interest to biologists, as well as to fishermen and processors. We accordingly combined length data by areas and performed *t*-tests or analyses of variance (the latter, for three or more years, between *years* and *periods*) on the larger resulting

tabulations. Expected seasonal growth is removed from the comparisons between years, of course, while significant interactions indicate different patterns of seasonal growth for the years involved in a particular analysis of variance.

Table 9 shows 10 results for years and five for interaction, from the 14 tests, to be significant. Differences in average size between years reflect changes either in the annual growth environments or in the response of successive stock units to those environments.

TABLE 9. Mean fork lengths (mm.), sample sizes (in parentheses) and results of comparisons for years and periods, all areas within a period combined from source data.

Life history group ¹	Year	Period (see p. 6)										Significance at .95 level	Inter action
		3	4	5	6	7	8	9	10	11	12		
<i>M-I-1</i>	1957	—	—	—	—	—	—	—	—	370(65)	—		
	1960	—	—	—	—	—	—	—	—	367(22)	—		
	1956	—	—	—	—	—	—	—	—	—	354(29)	*	
	1957	—	—	—	—	—	—	—	—	—	375(29)		
<i>F-I-1</i>	1957	—	—	—	—	—	—	—	—	363(44)	—	*	
	1960	—	—	—	—	—	—	—	—	348(34)	—		
	1956	—	—	—	—	—	—	—	—	—	358(17)		
	1957	—	—	—	—	—	—	—	—	—	368(32)		
<i>M-I-2</i>	1959	—	—	—	—	488(25)	486(74)	484(69)	496(65)	—	—	*	*
	1960	—	—	—	—	462(37)	474(160)	478(121)	482(29)	—	—		
<i>F-I-2</i>	1959	—	—	—	—	467(36)	470(50)	467(38)	—	—	—	*	*
	1960	—	—	—	—	449(38)	452(156)	461(160)	—	—	—		
	1957	—	—	—	—	—	—	—	479(45)	—	480(126)	*	
	1960	—	—	—	—	—	—	—	464(27)	—	476(39)		
<i>M-M-2</i>	1956	511(45)	519(30)	—	—	—	—	—	—	—	—		
	1959	539(71)	550(80)	—	—	—	—	—	—	—	—	*	
	1960	521(119)	525(154)	—	—	—	—	—	—	—	—		
	1957	—	—	541(42)	539(43)	—	—	—	—	—	—		
	1958	—	—	548(24)	535(20)	—	—	—	—	—	—	*	
	1959	—	—	544(134)	553(229)	—	—	—	—	—	—		
	1960	—	—	524(370)	527(370)	—	—	—	—	—	—		
	1956	—	—	503(58)	505(141)	—	—	—	—	—	—		
<i>F-M-2</i>	1957	—	—	519(76)	526(33)	—	—	—	—	—	—		
	1958	—	—	525(28)	511(36)	—	—	—	—	—	—	*	*
	1959	—	—	521(104)	523(320)	—	—	—	—	—	—		
	1960	—	—	498(223)	499(372)	—	—	—	—	—	—		
	1959	508(35)	522(54)	—	—	—	—	—	—	—	—	*	
	1960	490(49)	497(51)	—	—	—	—	—	—	—	—		
	1957	—	593(20)	—	611(37)	—	—	—	—	—	—		
	1959	—	604(24)	—	623(34)	—	—	—	—	—	—		
<i>F-M-3</i>	1957	—	573(25)	570(273)	—	—	—	—	—	—	—		
	1958	—	552(37)	571(32)	—	—	—	—	—	—	—		
	1959	—	578(24)	579(30)	—	—	—	—	—	—	—	*	*
	1960	—	567(26)	576(39)	—	—	—	—	—	—	—		
	1957	—	—	—	574(71)	574(33)	—	—	—	—	—		
	1959	—	—	—	585(84)	568(30)	—	—	—	—	—		*
	1957	—	—	—	—	—	—	—	—	—	—		
	1959	—	—	—	—	—	—	—	—	—	—		

¹ See note 1, Table 2.

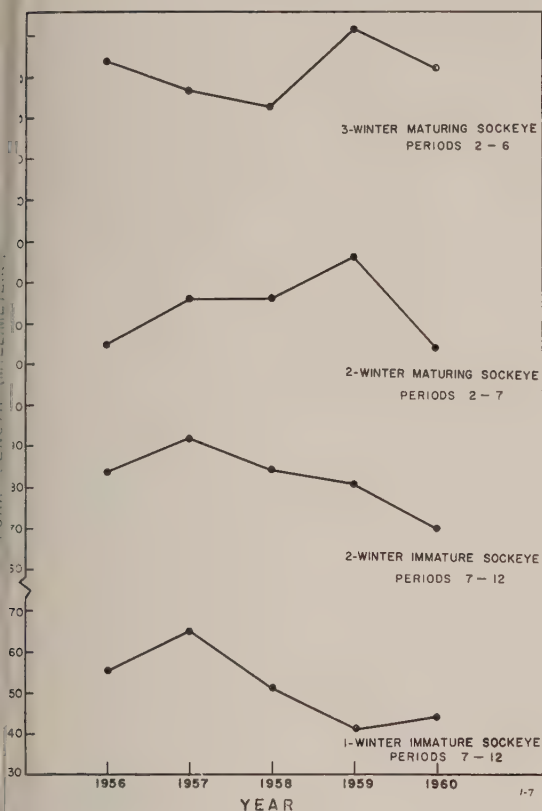


FIGURE 7. Annual mean fork lengths of Western Alaskan sockeye salmon, sexes combined, by maturity and winters at sea before capture. Means are from data pooled over 10-day periods.

Annual mean lengths in Figure 7 were computed and data were pooled for both sexes and all time periods within a year. Figure 7 demonstrates the range of length expected in Western Alaskan sockeye salmon, to the extent that the years 1956 through 1960 are a random sample of annual environment-response combinations.

COMBINATION OF DATA TO ESTIMATE GROWTH

To this stage, the analysis represents an effort to construct representative samples of mean size in Western Alaskan fish. It will be useful to review the eliminaries.

High seas sockeye salmon data were first classified by continental origin, by life history group and by time of capture. Western Alaskan fish were found to be significantly larger than Asian fish. Three criteria, believed to admit few Asian fish, were applied to available data in order to avoid this source of bias in

growth estimates of Western Alaskan sockeye salmon. Lack of weight records for fresh fish in the years 1956 through 1960, along with certain direct evidence of inaccuracy in length records for fresh fish in those years, were next noted to explain our use of laboratory data until conversions to average size of fresh fish were required to describe growth.

Catches from each life history group and allocation of mesh size by effort in U.S. research vessels, which took 88 percent of the data remaining at that stage of analysis, were found to contain no evidence of selectivity for size. Significant differences in average size of maturing fish between areas of capture were then held to be admissible in describing growth of all Western Alaskan fish. However, sampling coverage did not allow weighting these significant mean sizes to the relative abundance in respective areas of capture. Marked variations in mean size of fish in a given life history stage were then demonstrated between years of sampling. To build up samples large enough for describing, in particular, the seasonal growth, the years 1956 through 1960 were regarded as a random sample of annual environment-response combinations for Western Alaskan sockeye salmon.

Length and weight frequency data for all areas of capture and years of sampling were then summed. Numbers for some 10-day periods were judged too small to provide reliable estimates of mean size and were eliminated from further consideration. There-

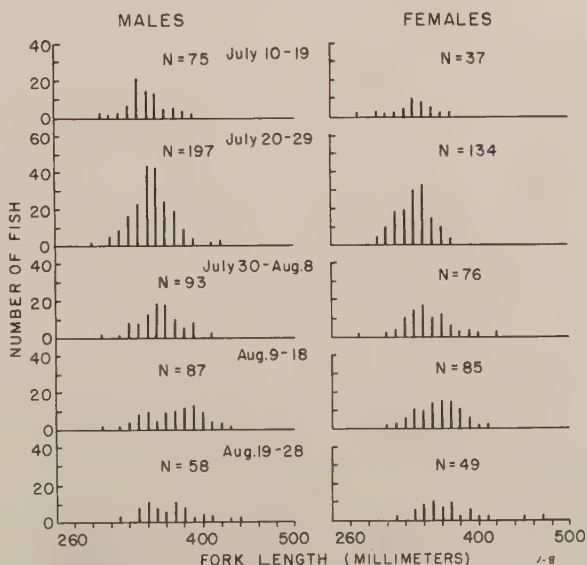


FIGURE 8. Fork length frequencies of immature sockeye salmon taken after one winter at sea.

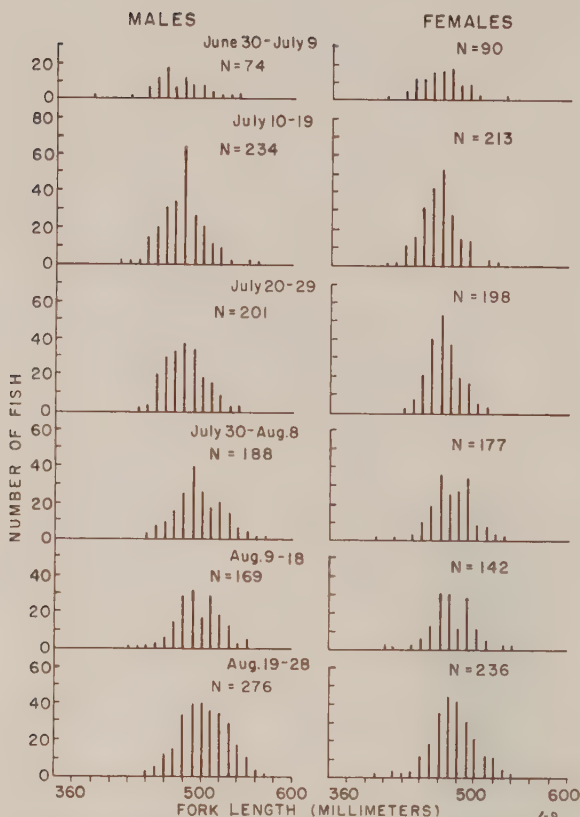


FIGURE 9. Fork length frequencies of immature sockeye salmon taken after two winters at sea.

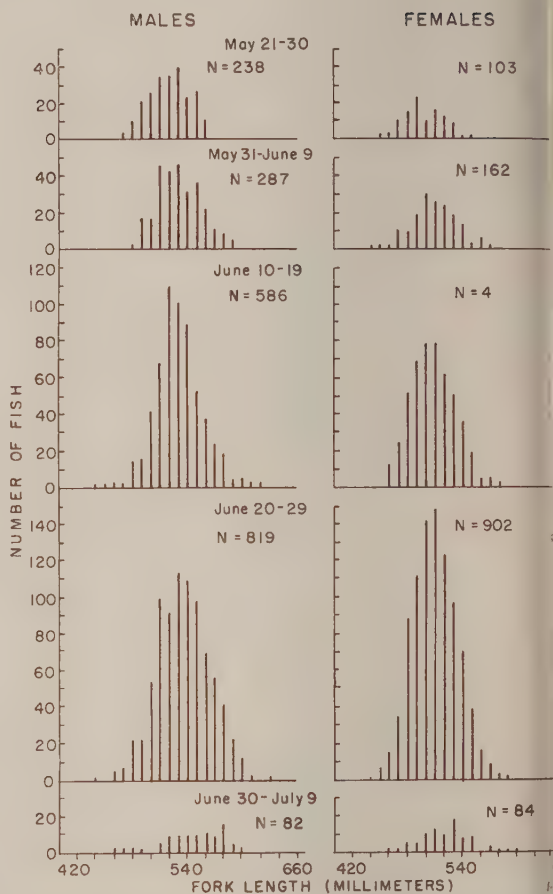


FIGURE 10. Fork length frequencies of maturing sockeye salmon taken after two winters at sea.

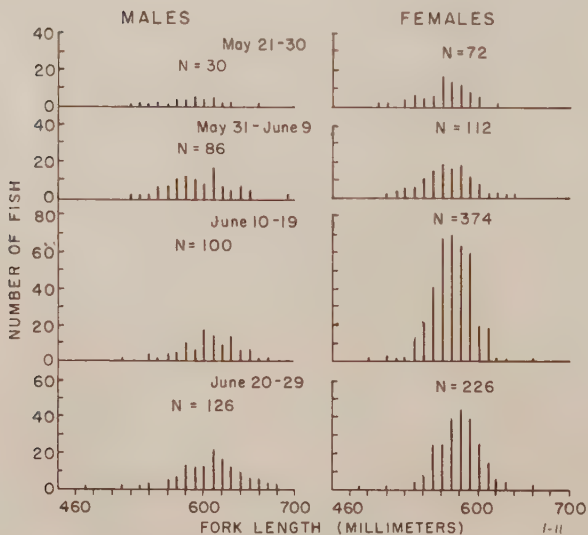


FIGURE 11. Fork length frequencies of maturing sockeye salmon taken after three winter at sea.

fore, of the 8,512 fish originally available for analysis, only 7,967 were actually employed as basis for growth estimates.

The following summary of numbers in each age-maturity combination gives a general idea of the relative precision to be expected in these growth estimates:

Age-maturity combination	Number of fish
1-winter immature	891
2-winter immature	2,198
2-winter maturing	3,752
3-winter maturing	1,126

Figures 8 through 15 show the composite size frequency data for estimating seasonal and long-term growth.

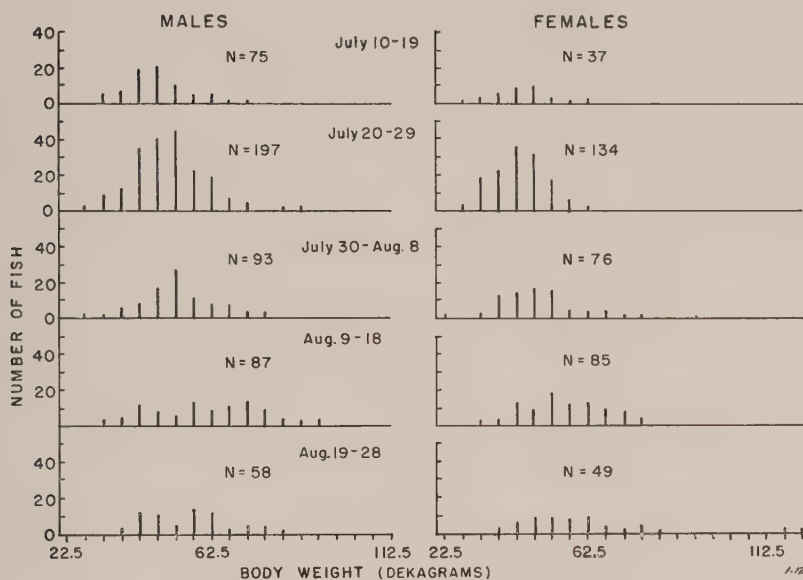


FIGURE 12. Body weight frequencies of immature sockeye salmon taken after one winter at sea.

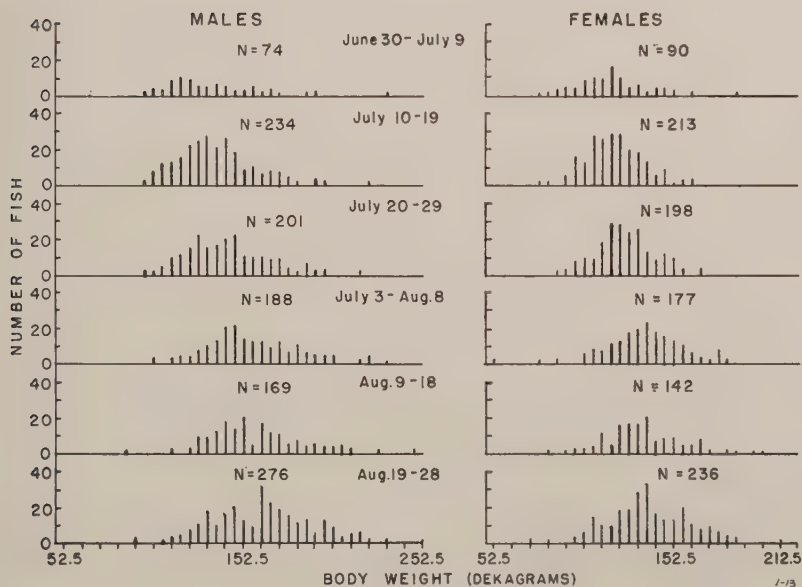


FIGURE 13. Body weight frequencies of immature sockeye salmon taken after two winters at sea.



FIGURE 14. Body weight frequencies of maturing sockeye salmon taken after two winters at sea.

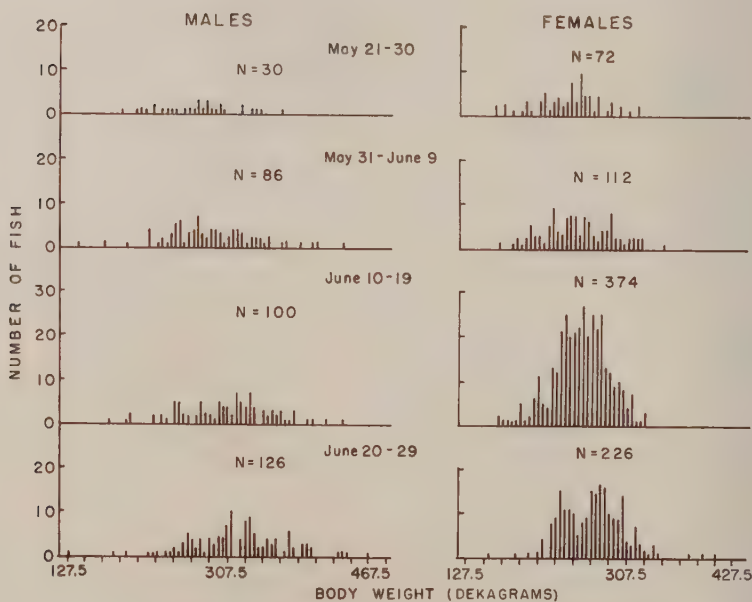


FIGURE 15. Body weight frequencies of maturing sockeye salmon taken after three winters at sea.

RESULTS

ESTIMATION OF SEASONAL GROWTH RATES

For each 10-day period and life history group, mean lengths and weights of fresh fish were next estimated by applying regressions in Figures 4 and 5 to the means of laboratory observations. Table 10 shows the resulting mean sizes of fresh fish. From the data of Table 10, Figures 16 and 17 were drawn to

TABLE 10. Estimated mean fork length and body weight of fresh fish, by 10-day periods, for each life history group (see note 1, Table 2) of Western Alaskan sockeye salmon.

Life history group	Period (see p. 6)	Mean fork length (mm.)	Mean body weight (dkg.)
M-I-1	8	356	50.4
	9	360	53.4
	10	368	56.2
	11	382	64.6
	12	378	60.1
F-I-1	8	347	46.6
	9	345	46.4
	10	359	52.0
	11	369	58.5
	12	378	61.4
M-I-2	7	484	131.1
	8	488	134.5
	9	491	140.5
	10	507	155.4
	11	508	156.2
	12	514	160.0
F-I-2	7	468	117.2
	8	468	118.5
	9	473	123.8
	10	484	134.7
	11	484	134.1
	12	488	136.9
M-M-2	3	533	191.1
	4	540	201.8
	5	540	205.6
	6	545	210.2
	7	557	215.8
F-M-2	3	508	160.0
	4	520	178.0
	5	518	179.3
	6	520	179.3
	7	532	188.9
M-M-3	3	596	264.3
	4	602	275.8
	5	612	295.3
	6	614	304.4
F-M-3	3	573	232.3
	4	574	240.7
	5	579	248.7
	6	586	259.3

shown time changes in mean length and weight, respectively, for each of the eight life history groups.

Growth in length could be calculated from the data of Table 10. Since growth in weight is more important in yield equations, however, the following discussion is in terms of weight rather than length. Also, the points in Figure 17 show males are heavier on the average than females. In order to estimate growth in weight for the stock as a whole, growth rates were not computed separately for each sex. Again, this could be done from the data of Table 10.

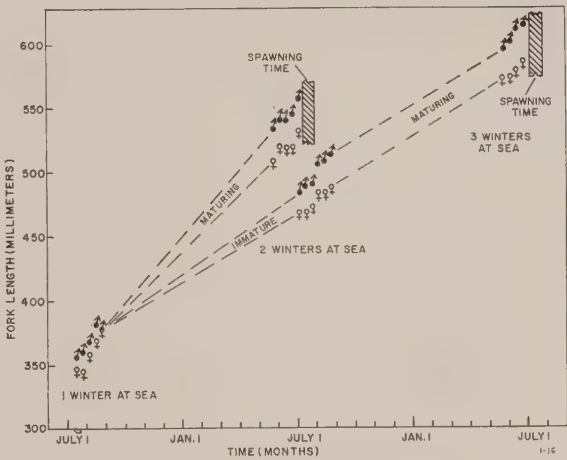


FIGURE 16. Mean fork length by 10-day period for each sampled life history group of Western Alaskan sockeye salmon. Light dashed lines indicate related groups, not linear growth, for periods not sampled.

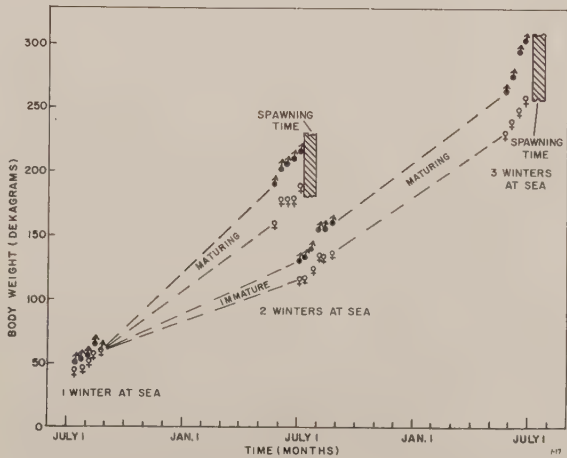


FIGURE 17. Mean body weight by 10-day period for each sampled life history group of Western Alaskan sockeye salmon. Light dashed lines indicate related groups, not linear growth, for periods not sampled.

TABLE 11. Least squares regressions of mean body weight (dekagrams) on 10-day period for each life history stage of Western Alaskan sockeye salmon. T refers to period number.

Life history stage	Regression equations
Immature after one winter at sea	$\hat{W} = 18.81 + 3.62 T$
Immature after two winters at sea	$\hat{W} = 85.26 + 5.44 T$
Maturing after two winters at sea	$\hat{W} = 161.78 + 5.84 T$
Maturing after three winters at sea	$\hat{W} = 213.62 + 11.44 T$

Two mean body weights occur in Table 10 for each 10-day period in which an age-maturity combination was sampled. For instance, mean body weights of 1-winter immatures sampled in period 8 are 50.4 and 46.6 dekagrams for males and females, respectively. The extent to which recorded numbers of each sex (see Figures 8 through 15) represent the true sex ratio in the several marine life history stages is unknown. Therefore, both such means were used without weighting for sample size in order to compute linear regressions of body weight on 10-day period for each age-maturity combination. The four combinations are referred to hereinafter as life history stages. Table 11 gives the regression equations for each life history stage; Figure 18 shows the resulting lines.

Finally, mean body weights were estimated from equations in Table 11 for the first and last 10-day periods in which a life history stage was sampled (see Table 10). These estimated means were considered applicable to the midpoints of the periods. Table 12 shows actual calculation of seasonal growth rates.

The above method of estimating seasonal growth rates—fitting straight lines to observed body weights, then converting percentage weight increases (or relative growth) to instantaneous rates—may warrant explanation. First, the appropriate growth model for longer periods than sampled here is not known, though exponential growth is commonly assumed (e.g., Ricker, 1958). Regressions of logarithm (to the base e) of body weight on 10-day period were calculated for each of the four life history stages before adopting the method of Figure 18 and Table 12. One such set of regressions¹ included weighting factors to account for the increasing variability (and hence lower precision) observed as the mean weight increased from one 10-day period to the next within a life history stage. A second set of logarithmic regressions did not contain these weighting factors. In both sets,

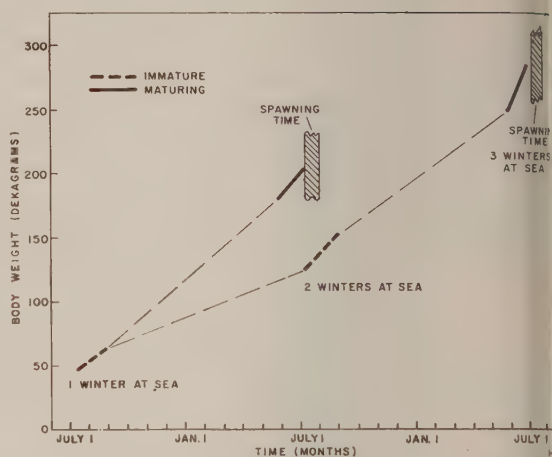


FIGURE 18. Regressions of mean body weight on 10-day period for each sampled life history stage of Western Alaskan sockeye salmon. Sexes are combined; light dashed line indicate related stages, not linear growth, for periods not sampled.

of course, slopes of regression lines yielded estimates of instantaneous growth rates. The estimated natural logarithms of average body weight were next antilogged to estimate actual body weights under both methods. Sums of squares of residuals between estimated and actual weights (the latter from Table 1) were then computed for the weighted exponential, unweighted exponential and arithmetic methods. The one method minimized the sums of squares of residuals for all four life history stages; had one method done so, calculations would have been shown here to more rigorously justify a choice. Moreover, total instantaneous growth rates in Table 12 were identical to the second digit for three of the four life history stages and identical to the first digit in all four stages, with the instantaneous rates from (slopes of) logarithmic regressions. Therefore, a simple arithmetic model (Figure 18 and Table 12) was judged adequate for the present description of growth.

Obviously, a refined model for seasonal growth of Western Alaskan sockeye salmon will require extended sampling. It is not assumed in Figure 18 or Table 12 that a linear arithmetic description will suffice for other times of year in Western Alaskan sockeye salmon, or indeed for other stocks of sockeye at the times here sampled. Conversions to instantaneous rates are presented in Table 12 because of interest in yield-per-recruit computations (e.g., Ricker, 1962).

ESTIMATION OF LONG-TERM GROWTH RATES

Figure 18 indicates that long-term growth may be estimated between the following paired life history

¹ Suggested by Dr. Gerald V. Paulik of the Fisheries Research Institute, University of Washington, Seattle, Washington.

TABLE 12. Seasonal growth rates within each sampled life history stage of Western Alaskan sockeye salmon.

Life history stage	Sampling periods (inclusive dates)		Number of days between period midpoints	Estimated body weight (dekagrams) at period midpoint		Percentage increase in body weight	Instantaneous growth rates ¹	
	Initial	Terminal		Initial	Terminal		Total	30-day average
Immature after one winter at sea	8 (7/10-7/19)	12 (8/19-8/28)	40	47.8	62.2	30	0.26	0.20
Immature after two winters at sea	7 (6/30-7/9)	12 (8/19-8/28)	50	123.3	150.5	22	0.20	0.12
Maturing after two winters at sea	3 (5/21-5/30)	7 (6/30-7/9)	40	179.3	202.7	13	0.12	0.09
Maturing after three winters at sea	3 (5/21-5/30)	6 (6/20-6/29)	30	247.9	282.3	14	0.13	0.13

Instantaneous growth rate, g , is defined as: $g = \log_e \left(\frac{\text{terminal weight}}{\text{initial weight}} \right)$, where e is the base of natural logarithms. See Ricker (1958) for a full explanation and for applications in fishery dynamics.

TABLE 13. Long-term growth rates between sampled life history stages of Western Alaskan sockeye salmon.

Life history stage		Midpoint of seasonal sampling, expressed as period number and date		Number of days between seasonal mid- points	Estimated body weight (dekagrams) at seasonal midpoint		Percentage increase in weight	Instantaneous growth rates ¹	
		Initial	Terminal		Initial	Terminal		Total	30-day average
Immature after one winter at sea	Immature after two winters at sea	10.0 8/3	9.5 7/30	360	55.0	136.9	149	0.91	0.08
Immature after one winter at sea	Maturing after two winters at sea	10.0 8/3	5.0 6/14	315	55.0	191.0	247	1.24	0.12
Immature after one winter at sea	Maturing after three winters at sea	10.0 8/3	4.5 6/10	675	55.0	265.1	382	1.57	0.07
Immature after two winters at sea	Maturing after three winters at sea	9.5 7/30	4.5 6/10	315	136.9	265.1	94	0.66	0.06

¹ See note 1, Table 12.

ages: (1) 1-winter immature and 2-winter immature, (2) 1-winter immature and 2-winter maturing, (3) 1-winter immature and 3-winter maturing, and (4) 2-winter immature and 3-winter maturing. Mean body weights of each of the four life history stages would be best approximated, from a statistical viewpoint, at their respective seasonal midpoints in time of sampling.

Therefore, mean body weights at midpoints of seasonal sampling were estimated from the regressions in Table 11. These means are the basis for long-term growth rates in Table 13. As in Table 12, the average 30-day instantaneous growth rates of Table

13 are not based on extrapolation from 10-day periods actually sampled.

DISCUSSION

Sampling extended only from May through August (see Table 12). This permitted no definition of growth patterns between September and April. Koo (1961) found all summer growth and, therefore, most growth in scales of chum salmon to occur between May and August; only the narrow "winter band" was deposited the rest of the year. From material collected in the Gulf of Alaska in March and April of 1962, new ocean scale growth is reckoned to start

approximately March 15 in 2-winter sockeye salmon and April 1 in 3-winter sockeye salmon¹. Yet the fish themselves grow considerably between September and April (see Figures 16 and 17). As mentioned earlier (Hanamura, MS), one cannot extrapolate scale radius to fish length over unsampled stages of life without invoking untested and perhaps inaccurate relationships. Therefore, sampling throughout the year is required to complete the growth picture begun in Figure 18.

Complete knowledge of short-term growth during the marine life of Pacific salmon may well require that at least three approaches be integrated: (1) direct observations on size of individuals, from sampling based on prior knowledge of quantitative distribution of the target stock; (2) tagging studies instituted with precise controls on quality of data; and (3) empirical definition of fish-scale relationships throughout life. Also, basic knowledge is required on endocrine and other mechanisms under genetic control and on such diverse environmental influences as food, temperature and population density.

Henry (1961) has related first-year marine growth, as estimated from scales, to the survival of Chilkot River sockeye between migration of smolts and return of spawners. Not yet understood are the mechanisms by which large numbers (of Adams River fish, in the case cited) evidently depress growth independently of survival in some years, while in other years poor growth and low survival go hand in hand. Clearly, further research is needed on short-term rates of marine growth and survival.

From knowledge of total ocean mortality and total number of months at sea, Ricker (1962) calculated average instantaneous monthly mortality rates for the entire ocean life of certain stocks of sockeye salmon. From evidence of very high mortality on small fish during their first year at sea, these average monthly rates were shown to be too high for 2-winter and older fish. Growth rates, estimated from scales and weight-length relationships, permitted computation of minimum losses in stock weight from high seas fishing. As mentioned in the introduction to the present report, these losses ranged from 6 percent to 40 percent, if offshore fishing were to be conducted during the year of maturity. From 50 percent to 65 percent of the potential inshore yield from a given recruitment would be lost to high seas fishing the year before maturity.

¹ Personal communication with Kenneth H. Mosher of the Age Analysis Unit, Bureau of Commercial Fisheries Biological Laboratory, Seattle, Washington.

SUMMARY

The objective of the study was to provide a basic description of marine growth for Western Alaska sockeye salmon. Approximately 88 percent of the specimens selected from available data were taken by gillnets fished by United States research vessels. Average mesh sizes, measured in inches between opposite knots of multifilament nylon stretched taut, were 2½", 3¼", 4½" and 5¼". Most of the remainder, 12 percent of the specimens were from 4.8" Japanese commercial nets. Sampling was conducted from 1956 through 1960 in the North Pacific Ocean and Bering Sea.

Immature 1-winter and 2-winter sockeye salmon were taken mainly in July and August; maturing 2-winter fish, from late May to early July; and maturing 3-winter fish, from late May to late June. Since sampling was not designed for estimating growth, to obtain a composite picture was more feasible than to attempt separate descriptions by year and area of capture.

Body weight, length, age, sex and gonad weight data were available from whole frozen specimens sent to the Bureau of Commercial Fisheries Biological Laboratory, Seattle, Washington. The authors collected data in 1961 to put earlier laboratory records on a fresh weight basis. For the years 1956 through 1960 fork lengths of fresh fish taken by United States research vessels were also on hand, along with data on the mesh size, time and location of capture.

Background studies of the International North Pacific Fisheries Commission provided criteria for determining maturity, means of separating Western Alaskan from Asian fish and information on the selective properties of gillnets used by United States research vessels.

The following sources of variation were considered in preliminary efforts to represent average size of Western Alaskan fish: (1) sex, maturity and winter at sea before capture; (2) changes in size between time of capture and time of laboratory processing; (3) area of origin; (4) use of gillnets known to be selective for size; (5) area of capture; and (6) year of capture.

Data were combined by sex, area of capture and year of capture in order to provide estimates of seasonal and long-term growth in weight for the entire stock. Percentage weight gains were converted to total and average 30-day instantaneous rates for the four sampled stages of marine life history.

The rationality of fishing Pacific salmon on the high seas both introduces and terminates the report. So discussed is the need for future research on short-term rates of ocean growth and natural mortality.

CONCLUSIONS

Maturing Western Alaskan sockeye salmon taken on the high seas are slightly but significantly larger, on the average, than Asian sockeye salmon taken at the same time. While indicated for all stages, this conclusion is uncertain for immatures because only matures were used to differentiate between stocks.

When each combination of sex, maturity and winters at sea is considered separately, use of graduated gillnet meshes provides substantially unbiased estimates of mean size.

Average size of maturing Western Alaskan sockeye salmon differs significantly between areas of capture. There are few such differences in mean size of immatures; here again, classification of immatures with respect to stock is uncertain.

Average size of Western Alaskan fish in a given life history stage changes considerably in different years of sampling.

Estimated total instantaneous growth in weight for 40 days in July-August is 0.26 for 1-winter immatures; for 50 days in June-August, 0.20 for 2-winter immatures; for 40 days in May-July, 0.12 for 2-winter maturing fish; and for 30 days in May-June, 0.13 for 3-winter maturing Western Alaskan sockeye salmon.

Long-term growth from the 1-winter immature stage on August 3 until the 2-winter immature stage on July 30 the following year is 0.91; from the 1-winter immature to 2-winter maturing stage on June 14 the following year, 1.24; and from the 1-winter immature to 3 winter maturing stage on June 10 two years later, 1.57.

From July 30 as 2-winter immatures until June 10 the next year as 3-winter maturing fish, Western Alaskan sockeye salmon were estimated to grow at a total instantaneous rate of 0.66.

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MORPHOLOGICAL CLASSIFICATION OF
MATURING SOCKEYE SALMON IN 1962

by Betty J. Landrum and Thomas A. Dark

The morphological characteristics of sockeye salmon from major sockeye salmon producing areas have been extensively examined since 1955 as a means of distinguishing the area of origin of salmon on the high seas, specifically in those parts of the North

Pacific Ocean and Bering Sea where it has been essential to determine the distribution and areas of intermingling of continental stocks as specified by the Protocol to the International Convention for the High Seas Fisheries of the North Pacific Ocean of 1952. Procedures and rationale for classification of sockeye salmon and the results of analyses of data from high seas samples collected in 1956 and 1957 are presented in Fukuhara *et al.* (1962). Collections of samples taken from 1958 to 1961 have been similarly classified and the resultant high seas distribution of Kamchatkan and Bristol Bay sockeye salmon described annually in reports to the Commission (Fukuhara, 1961; Landrum and Dark, 1963; Dark and Landrum, 1962).

High seas collections of maturing sockeye salmon taken in the summer of 1962 have been examined using morphological characteristics as the basis for classification to continental origin. Due to lack of *a priori* information (Dark and Landrum, 1962) immature fish taken on the high seas cannot be validly classified. Results of analyses of these data and comparisons with the distributions observed in previous years in the Bering Sea and North Pacific Ocean are reported herein.

SAMPLING

Six Bristol Bay streams were sampled approximately at the peaks of the runs. Stream escapements were estimated by the Alaska Department of Fish and Game and totalled 5,548 million sockeye salmon in Bristol Bay in 1962. Individual escapement estimates and numbers of fish collected from the Branch, Egegik, Kvichak, Naknek, Ugashik and Wood Rivers are given in Table 23.

In 1962 high seas samples were collected by two United States research vessels and from the catches of four Japanese motherships. Only samples containing 30 or more mature fish are discussed in this report. The samples available for analyses totalled 39. Most were obtained at locations from longitudes 170°E to 175°W, and south of the Aleutian Islands to approximately latitude 49°N. A smaller group of samples was taken from approximately longitudes 170°E. to 165°E. and latitudes 49° to 46°N. Only two samples of sufficient size were available from the Bering Sea, and one sample was collected south of Unalaska Island (Fig. 30). Eleven of the samples were collected in the latter part of May, one in mid-July and the remainder throughout June. Sampling dates and locations are given in Table 24.

CLASSIFICATION PROCEDURES

Using the discriminant function developed from data collected in 1956 and 1957 (Fukuhara *et al.*, 1962) and procedures for estimation of confidence intervals for point estimates, the percentages of specimens classified on the basis of morphological characteristics as Bristol Bay type salmon in the 1962 high seas and inshore samples were determined. This function has correctly classified mature sockeye salmon of known origin (e.g., stream samples) with quite consistent averages (76–83 per cent) since its initial development.

In stream samples from Bristol Bay rivers in 1962, the observed percentages of misclassified specimens were weighted by their respective relative abundance estimates, to provide a correction factor for the inherent errors in classification produced by the discriminant function in classifying salmon of known

TABLE 23. Average error in classification weighted according to relative abundance of the contributing stocks of Bristol Bay sockeye salmon in 1962.

Area	Escapement in millions	Relative abundance	Observed per cent of misclassification	Weighted value
Branch River	0.090	.0162	33.3	.53946
Egegik River	1.027	.1851	21.1	3.90561
Kvichak River	2.580	.4650	12.9	5.99850
Naknek River	0.723	.1303	21.4	2.78842
Ugashik River	0.255	.0460	10.8	.49680
Wood River	0.873	.1574	34.7	5.46178
Totals	5.548	1.0000		19.19057

Average errors of misclassification:

For the Bristol Bay population (Pa)=19.1906%.

For the Kamchatkan population (Pb)= $\frac{37.1681 + 33.6283}{2}$ = 35.3982%.

TABLE 24. Classification of high seas samples of mature sockeye salmon collected in 1962.

Sample number	Sampling date	Sampling position		Sample size	Per cent classified		Corrected per cent Bristol Bay type*	90 per cent confidence interval*
		Lat. N.	Longitude		Bristol Bay type	Kamchatkan type		
** 1	6-12	49°35'	166°26'E.	113	33.63	66.37	0.0	0 -16
** 2	6-12	49°22'	166°36'E.	113	37.17	62.83	3.9	0 -20
3	6-16	53°18'	166°55'E.	213	36.62	63.38	2.7	0 -15
4	6-12	48°32'	167°41'E.	103	38.83	61.17	7.6	0 -25
5	6-18	48°26'	167°48'E.	87	35.63	64.37	0.5	0 -19
6	6-18	48°26'	167°58'E.	95	42.11	57.89	14.8	0 -33
7	6-12	48°20'	168°12'E.	110	35.45	64.55	0.1	0 -17
8	6-12	47°42'	168°15'E.	88	28.41	71.59	0.0	0 -18
9	5-25	47°10'	168°50'E.	92	33.70	66.30	0.0	0 -18
10	5-25	47°23'	169°20'E.	96	29.17	70.83	0.0	0 -18
11	5-25	46°17'	169°53'E.	196	65.82	34.18	67.0	55-79
12	6-12	47°14'	169°56'E.	58	34.48	65.52	0.0	0 -23
13	6- 3	51°00'	170°00'E.	70	37.14	62.86	3.8	0 -25
14	5-25	52°16'	170°12'E.	107	39.25	60.75	8.5	0 -26
15	6- 1	52°00'	170°12'E.	43	34.88	65.12	0.0	0 -26
16	5-25	52°30'	170°23'E.	104	40.38	59.62	11.0	0 -28
17	6-25	51°10'	170°41'E.	33	36.36	63.64	2.1	0 -32
18	6-28	50°53'	171°11'E.	35	42.86	57.14	16.4	0 -47
19	6-10	50°23'	171°18'E.	194	39.69	60.31	9.5	0 -22
20	5-25	49°50'	171°18'E.	104	46.15	53.85	23.7	6 -41
21	5-25	50°02'	171°27'E.	108	62.96	37.04	60.7	44-78
22	5-31	50°15'	173°55'E.	115	57.39	42.61	48.4	32-65
23	5-31	50°30'	174°04'E.	118	64.41	35.59	63.9	48-80
24	6- 5	51°00'	176°00'E.	37	59.46	40.54	53.0	24-82
25	6- 6	49°47'	176°12'E.	82	31.71	68.29	0.0	0 -19
26	6- 6	51°20'	176°21'E.	110	69.09	30.91	74.2	58-90
27	6- 6	49°33'	176°45'E.	74	39.19	60.81	8.3	0 -29
28	6- 6	51°20'	176°57'E.	111	74.77	25.23	86.7	72-100
29	6- 6	50°56'	177°26'E.	109	60.55	39.45	55.4	38-72
30	6- 6	50°26'	177°26'E.	116	68.10	31.90	72.0	56-88
31	6- 2	50°09'	179°37'E.	200	51.00	49.00	34.4	22-47
32	6- 1	50°32'	178°33'W.	106	69.81	30.19	75.8	60-92
33	6- 1	50°46'	178°25'W.	110	64.55	35.45	64.2	48-81
34	6-16	54°01'	177°07'W.	65	87.69	12.31	100.0	82-100
35	5-31	51°22'	176°04'W.	108	67.59	32.41	70.9	55-87
36	6-11	50°57'	176°00'W.	39	53.85	46.15	40.6	12-70
37	6-19	53°28'	175°57'W.	33	66.67	33.33	68.9	39-99
38	5-31	51°14'	175°22'W.	103	73.79	26.21	84.5	69-100
39	7-12	52°52'	167°07'W.	42	71.43	28.57	79.3	54-100

* Percentage estimates truncated at 0 and 100.

** Kamchatkan reference sample.

Bristol Bay origin. In the absence of Kamchatkan stream samples, a correction factor for Kamchatkan fish misclassifying as Bristol Bay was estimated from two high seas samples obtained at times (mid-June) and locations (approximately latitude 49°N. and longitude 166°E.) which reasonably indicated that the fish were not from North America but originated on the Kamchatka Peninsula. The samples utilized for estimation of the average Kamchatkan error of misclassification

are numbers 1 and 2 in Table 24.

The estimated errors of misclassification in 1962 were 19.19 and 35.40 per cent for Bristol Bay and Kamchatkan populations, respectively. The Bristol Bay error of misclassification has remained rather uniform throughout the morphological studies. The average percentage of misclassification estimated for the Kamchatkan population was somewhat higher

than observed in most preceding years (24 to 29 per cent) but was very close to the error of misclassification (37 per cent) of a single stream sample taken from the Ozernaia River on the Kamchatka Peninsula in 1959 and to the average observed in 1961 Kamchatkan reference samples (37 per cent).

Using the calculated errors of misclassification to correct for misclassification of specimens taken on the high seas, point estimates of the percentage of Bristol Bay sockeye salmon present in each sample were estimated. Ninety per cent confidence intervals were calculated around the point estimates.

CLASSIFICATION OF NORTH PACIFIC OCEAN SAMPLES

Samples Taken Between Longitudes 165°E. and 170°E.

Of 11 samples collected in the most southwestern area in 1962, two were used as reference samples, six classified as 100 per cent Kamchatkan type sockeye salmon (Fig. 30). Point estimates for sample numbers 4 and 6 indicated that small portions of the samples could contain Bristol Bay salmon, but the 90 per cent confidence intervals for both estimates included zero. The estimates, therefore, could merely reflect variation in sampling Kamchatkan salmon. The samples were all taken from June 12–18, and this late in the season the maturing fish were unlikely to actually be of Bristol Bay origin.

Sample 11, taken on May 25, classified as 67 per cent Bristol Bay type. The confidence interval for the

estimate was 55–79 per cent. This offers reasonable evidence that Bristol Bay sockeye do occur in this western area at this time of the year.

Samples Taken Between Longitudes 170°E. and 175°E.

Samples taken from May 25 to June 28 between these longitudes south of the Aleutian Chain were classified as predominantly Kamchatkan type sockeye salmon. Bristol Bay type salmon dominated, 61 and 64 per cent, respectively, in sample numbers 21 and 23. The other nine samples in this group classified from 0 to 48 per cent Bristol Bay type, with an average classification of 14 per cent. The confidence intervals for seven of the 11 samples in the group ranged from 0 to 47 per cent with an average upper limit of 29 per cent. Sample numbers 20, 21, 22 and 23, classified respectively as 24, 61, 48 and 64 per cent Bristol Bay salmon, had an average confidence interval of 32 to 66 per cent, and none of the lower limits included zero.

Samples Taken Between Longitudes 175°E. and 180°

Classification of eight samples taken in this area from June 2 to June 6 indicated a dominance of Bristol Bay type sockeye salmon in five samples. Samples 24, 26, 28, 29 and 30 classified from 53 to 87 per cent Bristol Bay type, with an average of 68 per cent. Sample 25 contained no Bristol Bay salmon. Eight per cent of sample 27 and 34 per cent of sample 31 classified as Bristol Bay type salmon. The lower confidence limit for sample 27 included zero per cent, but the lower limit was 22 per cent for sample 31.

Samples Taken Between Longitudes 180° and 175°W.

Samples 32 and 33 were collected on June 1 and classified respectively as 76 and 64 per cent Bristol Bay salmon. Sample numbers 35, 36 and 38, taken May 31 and June 11 from longitudes 175° to 176°W., showed variable percentages of Bristol Bay salmon: 71, 41 and 84 per cent, respectively. Sample 36 had a large confidence interval (12–70 per cent) which can be attributed to the size of the sample, 39 specimens.

Other North Pacific Ocean Samples

Only two other samples, well separated from those discussed previously, were available for classification. Sample number 3, taken June 16 at latitude 53°18'N. and longitude 166°55'E., classified as only three per cent Bristol Bay type salmon; its confidence interval included zero. Sample 39, classified as 79 per cent Bristol Bay type, was taken south of Unalaska Island

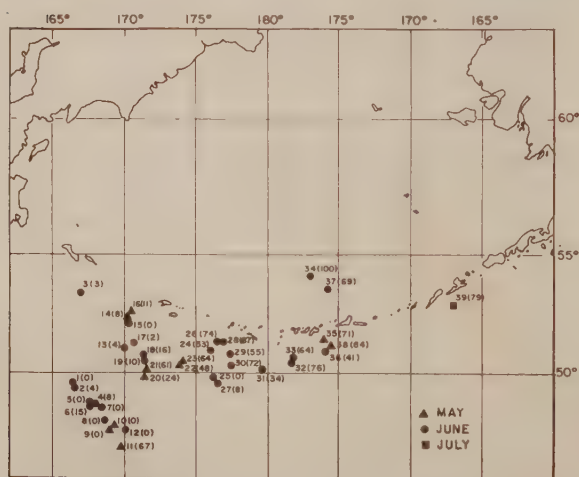


FIGURE 30. Percentages of maturing Bristol Bay sockeye salmon in high seas samples collected in May–July 1962. The first number designates the sample; the number in parentheses indicates the percentage classified as Bristol Bay salmon.

at latitude 52°52'N. and longitude 167°07'W. This sample was collected on July 12, later than the peak of the runs in Bristol Bay streams, and may have consisted in all or part of stocks from other North American areas, possibly Alaska Peninsula or Aleutian Island streams.

CLASSIFICATION OF BERING SEA SAMPLES

Sample numbers 34 and 37 at longitude 177°07'W. and latitude 54°01'N. and longitude 175°57'W. and latitude 53°28'N., respectively, consisted predominantly of Bristol Bay type salmon. Sample 37, with only 33 fish, had a large confidence interval, 39 to 99 per cent, and the interval for sample 34, with 65 specimens, was 82 to 100 per cent.

SUMMARY AND CONCLUSIONS

During May to July of 1962, sockeye salmon were collected in the North Pacific Ocean and Bering Sea for morphological studies. Samples of less than 30 specimens were excluded. This left 39 samples for determining distributions of continental stocks on the high seas in 1962, of which 37 were collected in the North Pacific Ocean, all but one west of longitude 175°W. Two samples were collected in the Bering Sea west of longitude 175°W.

Two obvious sampling problems hindered the analysis. One was the absence of samples from or near the sockeye salmon producing areas of the Kamchatka Peninsula for use as estimators of the Kamchatkan errors of misclassification. The best samples available and used for this purpose were collected in June several hundred miles off the southeastern coast of Kamchatka. Presence of maturing Bristol Bay salmon in abundance in this area is unlikely. The second sampling problem was that paucity of samples severely limited determination of the general high seas distribution of continental stocks, except in one rather restricted zone of the North Pacific Ocean.

The incidence of Bristol Bay type sockeye salmon increased eastward from longitude 175°E., predominating in the majority of the samples. Variability among samples indicated some intermingling of continental stocks or the inclusion of local stocks from areas other than Bristol Bay or Kamchatka. West of longitude 175°E. Kamchatka sockeye salmon dominated in all but three samples. The other samples classified as 0-24 per cent Bristol Bay type salmon.

On the basis of the available samples taken in 1962, the high seas distribution of maturing Bristol Bay and Kamchatkan sockeye salmon in the North Pacific

Ocean and Bering Sea was quite consistent with results of previous years.

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ANALYSIS OF SCALE CHARACTERS

Morphological, serological and tagging results have defined in various degrees the distribution and intermingling of salmon stocks originating in North America and Asia. Scale characters are now supplanting meristic characters in defining areas of origin. Scales are economical to collect, convenient to process and easy to exchange with other fishery agencies.

Present procedures begin with collection of a scale sample from a specified body area, and preferably with selection of a particular scale from within that area (p. 115, Annual Report 1961, INPFC). Careful counts of circuli and measurements of growth zones are next made in the laboratory from plastic impressions of the scales. Useful data are then selected by statistical tests. Determination of the area of origin follows from analyses of the frequency distributions of one, two, or several scale characters.

Research on pink and sockeye salmon scales is reported here; the section entitled "Chum Salmon Morphology Studies" given progress on chum salmon. Investigation of chinook and coho salmon scales and sockeye in the Gulf of Alaska, preliminary at this time, are not reported.

Some Alternative Premises for Constructing Theoretical Reproduction Curves¹

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ABSTRACT

Various types of reproduction curves have found extensive use in management and analysis of fish populations. To these may be added curves based on depensatory processes of mortality. Life-history stages may be considered as successive "stock and recruitment" relationships, the output from one process comprising the input of the next. A variety of reproduction curves can thus be generated by considering differing sequences of compensatory and/or depensatory processes.

REPRODUCTION CURVES have been extensively used in management and analysis of fish populations since their development by Ricker (1954). Some types of curves which have been reported are shown in Fig. 1-4 and include:

- (1) Compensation curves of the family

$$Z = we^{a(1-w)} \quad (1)$$

which describe a compensatory population regulation, progressively more severe in compensation with increase in stock size (Ricker, 1954).

- (2) Quotient curves of the type

$$Z = \frac{w}{1 + A(w - 1)} \quad (2)$$

suggested by Beverton and Holt (1957), which describe an asymptotic compensation mechanism.

- (3) Empirical curves, based either on reasonable premise (e.g. Ricker, 1958a, curves F and G; and Ricker, 1958b, for various kinds of situations), or based on curves fitted to observation (e.g. Shepard and Withler, 1958).

- (4) Modified compensation curves of the form

$$Z = we^{a \operatorname{sgn}(1-w)a|1-w|^b} \quad (3)$$

in which the modifying exponent b is added to the term $(1-w)$ treated as positive, but preserving the sign of $(1-w)$ as an exponent of e . Curves of this family (Fig. 3 and 4) introduce sinuosities into the stock-recruit relation which may be useful in simulating some natural situations, for example, when territorial behavior prevents supersaturation of spawning areas (Di Costanzo, personal communication).

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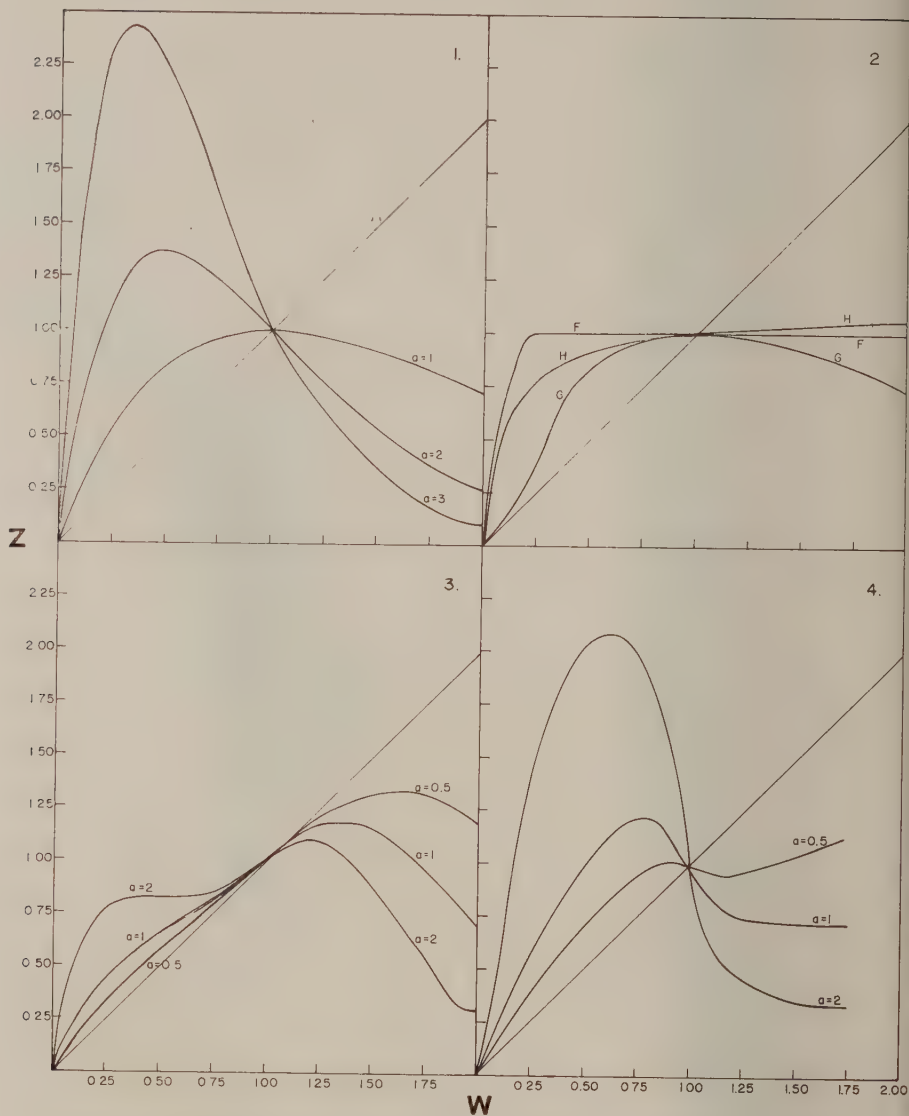


FIG. 1. Reproduction curves based on the compensation formula $Z = wea(1-w)$

FIG. 2. Various reproduction curves after Ricker (1958a, b).

$$\begin{aligned}
 \text{(F)} \quad Z &= wea(1-w), & a &= 2 \text{ up to } 1.0 \\
 \text{(G)} \quad Z &= wea(1-w), & a &= 1 \text{ beyond } w = 0.4 \\
 \text{(H)} \quad Z &= \frac{w}{1 + A(w-1)}, & A &= 0.9
 \end{aligned}$$

FIG. 3. Modified compensation curves with the formula $Z = wea(1-w)^b$ where $b = 2$.

FIG. 4. Modified compensation curves with the formula $Z = wea(1-w)^b$ where $b = 0.5$.

This paper outlines some alternative premises for constructing theoretical reproduction curves, and deals largely with the consequences of considering life history stages as successive "stock and recruitment" relationships.

DEPENSATION CURVES

Ricker (1954) presented a classification of predation into three types:

"A" in which a fixed number of prey are taken,

"B" in which predators at any given abundance take a fixed proportion of prey, and

"C" in which predators take all of the prey in excess of a certain number.

The familiar compensation curve represented by equation (1) results from a formulation of cannibalism, but may also be related to Type B predation if there is a numerical response by the predator.

The consequences to a stock-recruitment relation of Type A predation and Type B predation with a fixed number of predators, *if they were the only factors operating*, are shown in Fig. 5. Type A predation expressed as a consequence in a stock-recruitment relation has the form

$$Z = we^a - C \quad (4)$$

where C is the fixed number of prey taken by the predator. As indicated in Fig. 5, the population will increase or decrease indefinitely depending on whether we^a is greater or less than C . The proportion taken by the predator is smallest for the largest populations, the ratio of Z to W increasing with increase in W .

Type B predation for a given abundance of predators expressed in terms of its consequences to the stock-recruitment relation has the form

$$Z = we^{a-b} \quad (5)$$

where b represents the fixed instantaneous rate of mortality caused by the predator. Curve F of Fig. 5 where $C = 0$ is an example. The ratio of Z to w is a constant, and provided $a > b$ the population increases indefinitely.

Types A and B may be combined into the more general form

$$Z = we^{a-b} - C \quad (6)$$

which may be called a linear depensation curve wherever C is greater than zero.

An alternative depensation curve is provided by

$$Z = we^{aw} - C \quad (7)$$

a process which relates the intensity of depensation logarithmically to density.

An obvious feature of the above depensation curves is the implication that at certain stock densities all of the prey will be "captured". It would seem more reasonable to suppose that at even the lowest densities of stock some prey would survive. In more general terms, for any depensatory process, it might be expected that there would not be a sharp threshold below which all prey are taken, but rather there would be a continuous and decreasing effect at increasing

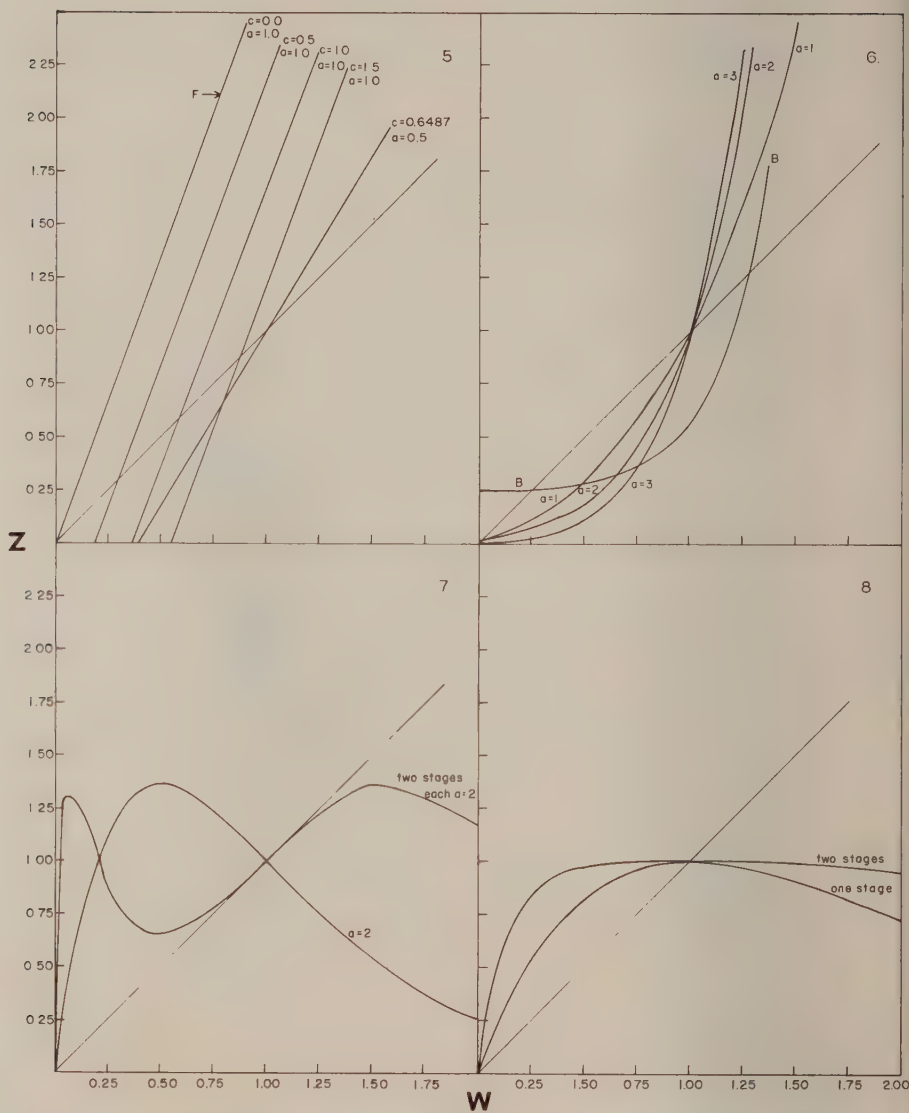


FIG. 5. Depensation curves of the general formula $Z = we^{a-b} - C$ which represent the types of reproduction curves which would result from fixed number and/or fixed percentage predation.

FIG. 6. Curvilinear depensation expressed in the stock-recruit relationship $Z = we^{a(w-1)}$. Curve B has the added constant $R = 0.25$ and $a = 3$.

FIG. 7. Reproduction curve resulting from a two-stage life history in which the relation between input and output at each stage is given by $Z = we^{a(1-w)}$, where $a = 2$. The simple one-stage reproduction curve for $a = 2$ is given for comparison.

FIG. 8. Reproduction curves resulting from a two-stage life history in each stage of which $Z = we^{a(1-w)}$ where $a = 1$. The simple one-stage reproduction curve is given for comparison.

density. An obvious choice for a curvilinear depensation process that would result in a stock-recruit relationship that would go through the origin is

$$Z = we^{a(w-1)}. \quad (8)$$

This formula is the converse of Ricker's compensation process. It also solves to give $Z = 1$ when $w = 1$, an advantage when dealing in units of stock. Figure 6 gives some examples of curves of this group. An unlikely feature is the exaggerated benefit which large stock sizes gain from depensation, which is easily rectified by supposing that there is no depensation beyond one unit of stock.

It might also be supposed that at densities of prey *below* a certain threshold, no prey would be taken by predators, simulating for example, a refuge for a certain number of stock units of prey. This type of situation, expressed in terms of its consequences to a stock-recruit relationship, is given by

$$\begin{aligned} Z &= R + (f_1)(w - R) & w > R \\ &= (f_2)w & w < R \end{aligned} \quad (9)$$

where the function f_1 of w could conform to Type A predation (thus eating the surplus or a fixed number whichever is least); Type B predation (eating a fixed fraction above a threshold) or to the curvilinear depensation process represented in equation (7), i.e.

$$\begin{aligned} Z &= R + (w - R)e^{a(w-R-1)} & w > R \\ &= (f_2)w & w < R. \end{aligned} \quad (10)$$

A curve of this type is given by curve B, Fig. 6, using $a = 3$ and $Z = R$ below $w = 0.25$.

LIFE-HISTORY STANZAS

The life history of many species of animals may conveniently be divided into stanzas within which compensatory or depensatory types of mortality may be characteristic. Although it can be deduced that a population can only be in equilibrium in the long term when there is an overall compensatory reproductive curve, it is nevertheless likely that this compensation is a consequence of various kinds of processes at different life-history stages. Accordingly, it seems appropriate to construct for each convenient segment of the life history a curve relating input to output which describes compensatory, depensatory or more complex kinds of effects.

Figure 7 is a simple example, representing the type of reproduction curve that results from a two-stage life history, with compensation according to the familiar form

$$Z = we^{a(1-w)}$$

with $a = 2$ in *each* stage. This kind of curve can be constructed very simply by calculating, say, Z_1 for a given w_1 , then using this value of Z_1 for w_2 in the imagined second stage. The final Z_2 is then plotted against w_1 to give a reproduction curve relating parents to adult progeny of the generation. In this type of system, maximum production results from either a small or quite

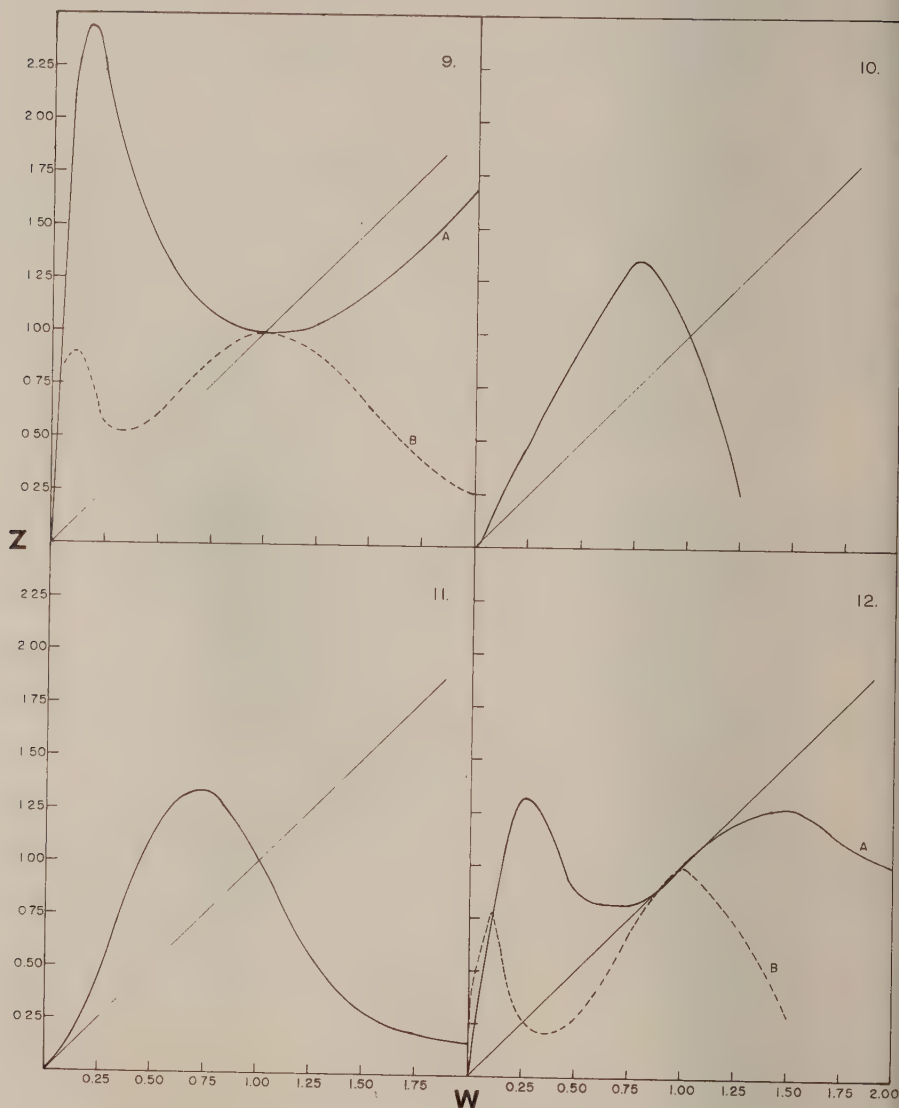


FIG. 9. Reproduction curves resulting from a two-stage life history, with compensation in each stage according to $Z = wea(1-w)$. Curve A, $a = 1, 3$, Curve B, $a = 3, 1$.

FIG. 10. Reproduction curve resulting from a two-stage life history, with depensation in the first stage, $Z = wea(w-1)$ where $a = 2.0$ and compensation in the second stage, $Z = wea(1-w)$ where $a = 2.0$.

FIG. 11. Reproduction curve resulting from a two-stage life history with compensation ($Z = wea(1-w)$, $a = 1.5$) preceding depensation ($Z = wea(w-1)$, $a = 2.0$).

FIG. 12. Reproduction curves based on three life-history stages. A. Two stages each with compensation with $a = 1.5$, one stage of depensation $a = 2.0$. B. Two stages of compensation with $a = 3, 1$, one stage of depensation $a = 2.0$.

substantial stock, with a dip between reflecting the compensation in the second life-history stage.

The two-stage reproduction curve where $a = 1$ (Fig. 8) is similar in form to the curve for the quotient relationship of Beverton and Holt (1957), suggesting the possibility that two moderate compensations could have the effect of making recruitment relatively constant over a wide range of stock densities.

Where the value of a is large in the second stage of a two-stage compensation process, the resultant curve may imply the unlikely situation where very small or very large stocks give the greatest recruitments (Fig. 9A). In the more plausible case where the most severe compensation occurs in the first life-history stage, the resultant of two-stage compensation also shows two peaks, with greater production resulting from the larger stock (Fig. 9B).

Two-stage reproduction curves may also be constructed so that one stage is a depensation process. Figure 10 shows the resultant of a two-stage process, the first stage of which is the depensation curve

$$Z = we^{a(w-1)}$$

where $a = 2.0$ and the second stage of which is compensation with $a = 2.0$. Figure 11 shows a two-stage process in which compensation precedes depensation. The resultant curve exhibits some similar properties to the curve G of Ricker (1958a).

Three-stage reproduction curves, though constructed to parallel what seem to be reasonable circumstances, may result in rather bizarre representations of population events. Curve A of Fig. 12 describes a population which would respond only slightly to moderate displacement from equilibrium, but would increase beyond unit stock size if reduced to 0.25 unit. Curve B is quite unrealistic, representing a stock which would oscillate about a low level, never achieving unit stock size if ever displaced therefrom.

DISCUSSION

In discussing various deviations from the compensation type of reproductive curve of equation (1), Ricker (1958b) indicated the possibilities for considerable variety in stock-recruit relationships. In each instance it was implied that a mechanism operating at some particular stage of the life history might be responsible for the characteristic shape of the reproduction curve.

Where several different life-history stages are characterized by a potential for influencing the numerical output depending on the size of the input, there are still further opportunities for modifying stock-recruit relations summarizing the whole life cycle. An example of a reproductive curve involving a three-stage life-history process, in which the first stage is compensatory, the second depensatory and the third extrapensatory, is described in Ward and Larkin (MS, 1963) in a model depicting cyclic dominance in the Adams River race of sockeye salmon.

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DIRECTION OF MOVEMENT OF SALMON IN THE NORTH PACIFIC OCEAN, BERING SEA AND GULF OF ALASKA AS INDICATED BY SURFACE GILLNET CATCHES, 1961

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Seattle, Washington, March 1963

ABSTRACT

Direction of movement of sockeye, chum and pink salmon on the high seas is described for the spring and summer months of 1961. Individual direction estimates are obtained from surface gillnet catches by applying the side of the net in which the fish were gilled to the average direction of the lay of the net string.

The results indicate, for sockeye salmon, eastward movement in the eastern Bering Sea, westward movement in the western Bering Sea and western Gulf of Alaska during the spring. In the summer, sockeye salmon move northward in the North Pacific Ocean and westward along the Aleutian Chain. Chum salmon move westward in the Bering Sea and western Gulf of Alaska during the spring months and follow the sockeye salmon pattern in the summer. The few usable pink salmon results indicate a northward movement in the north-central North Pacific Ocean and westward movement in the Bering Sea and western Gulf of Alaska.

In areas of comparable sampling, these direction estimates are similar to those obtained from 1961 purse seine catches and as described by Johnsen (1964) for 1959 and 1960 gillnet catches and Hartt (1962) for 1956 to 1958 purse seine catches.

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INTRODUCTION

As the research agency of the United States Section of the International North Pacific Fisheries Commission, one phase of the work of the Bureau of Commercial Fisheries has been to conduct gillnet salmon

sampling on the high seas of the North Pacific Ocean, Bering Sea and Gulf of Alaska from 1955 through 1961. Our sampling program is designed to collect salmon for racial analysis, to obtain data for distribution and abundance studies and to study the oceanographic conditions related to salmon distribution and abundance.

Important in the study of salmon distribution and abundance is the direction of travel of the fish encountered on the high seas. By observing this direction at successive intervals in space and time, an indication of migration routes may be obtained.

The application of accurate direction data extends to the problems of determining precise migration routes and continent of origin of high seas caught salmon, and properly interpreting gillnet catches for relative abundance studies.

This report will discuss the analysis of the direction of travel of sockeye (*Oncorhynchus nerka*), chum (*O. keta*) and pink salmon (*O. gorbuscha*) in 1961 as indicated by surface gillnet catches.

PROCEDURES

In 1961, as in past years, the high seas sampling was carried out on chartered fishing vessels. The season began in mid-April with the departure from Seattle of the MV *Marine View*, a 75-foot herring seiner, and MV *Paragon*, an 81-foot halibut schooner, for the central and western Aleutian area. In late May, the 72-foot herring seiner MV *Windward* departed for the western Gulf of Alaska, and in early August a converted Navy AKL (light cargo vessel), the 176-foot MV *Bertha Ann*, left for the central and northern Gulf of Alaska.

Paragon fished in the Bering Sea and western North Pacific until early July, *Marine View* worked the central North Pacific and Bering Sea until late August, *Windward* covered the area south of Kodiak until early September and *Bertha Ann* fished the northern and central Gulf of Alaska until early

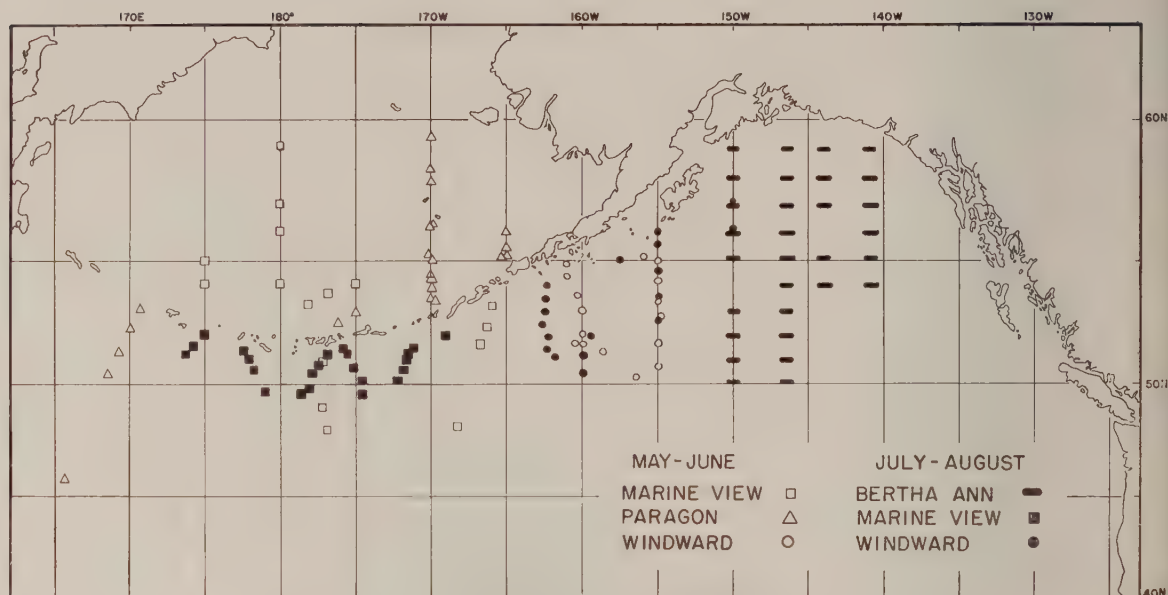


FIGURE 1. Fishing stations of United States research vessels in 1961.

October. Figure 1 shows the stations fished by the four research vessels.

Each vessel was equipped with a 2,000 fathom string of gillnets consisting of 40 shackles of varying mesh sizes and appropriate spare nets for repairs. The only change in the gear from 1959 and 1960 was the addition of four shackles of 3 7/8-inch mesh nets, making a string of four 2½-inch mesh nets, four 3¼-inch mesh nets, four 3 7/8-inch mesh nets, twenty-four 4½-inch mesh nets, and four 5½-inch mesh nets. At various times through the season this proportion was temporarily changed due to net loss or damage. For complete gear description and make-up see Johnsen (1964) and Hanavan and Tanonaka (1959).

The normal fishing routine consisted of setting the nets at dusk, letting them fish through the night, and hauling an hour or so after dawn. As the nets came aboard, the fish were removed from the nets, and the side of the net from which the fish were gilled, left or right looking from the vessel, was recorded on a tally board. Each fish was marked by clipping either the left or right pelvic fin to retain direction identity throughout processing and placed in bins on deck corresponding to mesh size. The nets were then repiled on the afterdeck in readiness for the next evening's set. When the haul was completed the fish were measured, scale samples taken and the fish frozen for further study in the laboratory.

To determine the direction of travel of the individual fish, the magnetic heading of each shackle was recorded as the nets were hauled. These individual headings were then averaged to give the mean string direction during hauling. This information, when combined with the side of the net from which the fish were gilled, gave an indication of direction of travel by adding 90° to the string direction for left fish and subtracting 90° from the string direction for right fish. For the purposes of this study the direction of movement assigned to the fish is perpendicular to that of the net string although the possible angle of entry into a gillnet approaches 180°. The resulting direction of travel, in degrees, was then corrected for variation to express direction in true degrees.

To minimize handling and classification errors (estimated by Johnsen to be in the order of 10%), and variations in net direction, the following five criteria were applied to each set: (1) length of set: between 8 and 14 hours; (2) net swing: maximum of 90°; (3) individual net variation (within the string): maximum of 90°; (4) 60 percent or more dominance of direction; (5) 20 or more fish of a particular species. Only those sets which met all five criteria were accepted for direction analysis.

Judging from our experience in past seasons and according to Cleaver (MS), the May and June catches

of sockeye salmon are primarily of mature fish and the July, August and September catches are of immature fish in the Bering Sea and Aleutian Islands area. Available maturity data for 1961 show that this maturity separation does not hold for the North Pacific Ocean south of 50°N. or the Gulf of Alaska or for chum salmon.

The maturity study of 1961 catches had not been completed at the time of writing so a presentation of direction of travel for mature and immature salmon separately was not possible. Where maturity is known for a particular area, the fact is mentioned in the results section.

Because of the wide possible angle of entry into the nets and the fact that the direction of set influences

the assignment of direction (nets that are set to the south or to the north may have only east or west directions assigned), the individual direction assignments must be regarded as estimates with the possibility of a 90° error to either side of the assignment. Regardless of the limitations of the method we can at least be positive that the majority of the fish was not moving in a direction opposite to the assigned direction. For example, a direction assignment of east would indicate that the fish could be moving north-northeast or south-southeast but not west.

RESULTS

The four research vessels spent a total of 12 vessel-months at sea and fished 126 stations. Elimination of sets that did not qualify under the five criteria for

TABLE 1. Assignment of direction of movement to sockeye salmon caught in gillnets, 1961.

Vessel	Set number	Haul date	Location		Number left	Number right	Total	Percent direction	Haul direction	Individual net variation	Net swing	Predominant direction of travel
			Latitude	Longitude								
<i>Paragon</i>	7	6/10	53°N	175°W	2	20	22	91R	126°	70°	64°	036°
	8	6/12	53.5°N	170°W	60	5	65	92L	022°	60°	10°	112°
	11	6/16	56°N	170°W	17	52	69	75R	233°	25°	31°	143°
	12	6/17	58°N	170°W	0	139	139	100R	218°	85°	25°	128°
	13	6/18	59°N	170°W	2	14	16	88R	204°	65°	34°	114°
	14	6/19	58.5°N	170°W	3	47	50	94R	202°	55°	9°	112°
	19	6/25	53.5°N	170°W	59	12	71	83L	237°	30°	22°	327°
	22	6/29	56°N	165°W	7	147	154	95R	233°	60°	38°	143°
<i>Marine View</i>	10	6/18	53.5°N	176.5°W	11	65	76	86R	225°	30°	13°	135°
	11	6/19	53.5°N	178°W	8	68	76	89R	158°	80°	32°	068°
	13	6/21	56°N	180°	47	7	54	87L	034°	10°	27°	124°
	14	6/23	57°N	180°	21	11	32	66L	240°	35°	8°	330°
	15	6/25	59°N	180°	32	12	44	73L	220°	40°	11°	310°
	16	6/27	55°N	175°E	25	13	38	66L	191°	30°	8°	281°
	20	7/12	50.5°N	177.5°W	6	14	20	70R	059°	90°	6°	329°
	24	7/24	50.5°N	178.5°W	46	8	54	85L	269°	60°	7°	359°
	25	7/25	51°N	178°E	134	19	153	88L	174°	40°	12°	264°
	28	7/29	51.5°N	174.5°E	84	27	107	79L	212°	60°	28°	302°
	29	7/30	51°N	174°E	220	58	278	79L	201°	30°	17°	291°
	32	8/6	50.5°N	175°W	32	13	45	71L	245°	20°	10°	335°
	33	8/7	50°N	175°W	60	27	87	69L	305°	70°	48°	035°
	35	8/10	50°N	172°W	11	18	29	62R	090°	30°	34°	000
<i>Windward</i>	40	8/17	51°N	168.5°W	6	38	44	86R	299°	20°	29°	209°
	2	6/8	53.5°N	160.5°W	3	967	970	100R	356°	10°	40°	266°
	5	6/15	55°N	156°W	11	72	83	87R	342°	75°	17°	252°
	6	6/16	54.5°N	155°W	7	20	27	74R	334°	25°	15°	244°
	10	6/20	51.5°N	155°W	112	11	123	91L	205°	40°	40°	295°
	18	7/10	53.5°N	163°W	0	33	33	100R	349°	40°	21°	259°
	20	7/12	52.5°N	162.5°W	29	58	87	67R	347°	70°	52°	257°
	24	7/25	50.5°N	160°W	47	14	61	77L	231°	40°	81°	321°
	25	7/26	51.5°N	160°W	48	18	66	73L	188°	35°	42°	278°
	26	7/27	52°N	160°W	20	2	22	91L	205°	20°	5°	295°
<i>Bertha Ann</i>	6	8/21	53°N	150°W	20	4	24	83L	233°	30°	30°	323°
	7	8/22	52°N	150°W	32	11	43	74L	232°	20°	15°	322°

TABLE 2. Assignment of direction of movement to chum salmon caught in gillnets, 1961.

Vessel	Set number	Haul date	Location		Number left	Number right	Total	Percent direction	Haul direction	Individual net variation	Net swing	Predominant direction of travel
			Latitude	Longitude								
<i>Paragon</i>	2	5/29	53.5°N	171°E	3	20	23	87R	349°	25°	11°	259°
	13	6/18	59°N	170°W	16	10	26	62L	204°	65°	34°	294°
	19	6/25	53.5°N	170°W	57	9	66	86L	237°	30°	22°	327°
<i>Marine View</i>	5	5/21	48°N	168°W	40	11	51	78L	183°	40°	35°	273°
	10	6/18	53.5°N	176.5°W	22	5	27	81L	225°	30°	13°	315°
	17	6/28	54°N	175°E	43	21	64	67L	197°	10°	13°	287°
	19	7/11	51°N	177.5°W	5	41	46	89R	113°	20°	60°	023°
	21	7/13	50°N	178°W	8	16	24	67R	072°	10°	19°	342°
	24	7/24	50.5°N	178.5°E	42	17	59	71L	269°	60°	7°	359°
	25	7/25	51°N	178°E	46	16	62	74L	174°	40°	12°	264°
	27	7/27	52°N	175°E	14	67	81	83R	067°	75°	19°	337°
	28	7/29	51.5°N	174.5°E	18	9	27	67L	212°	60°	28°	302°
	29	7/30	51°N	174°E	42	19	61	69L	201°	30°	17°	291°
	32	8/6	50.5°N	175°W	47	16	63	75L	245°	20°	10°	335°
	33	8/7	50°N	175°W	135	19	154	88L	305°	70°	48°	035°
	34	8/8	49.5°N	174.5°W	18	41	59	69R	302°	70°	23°	212°
	35	8/10	50°N	172°W	12	39	51	76R	090°	30°	34°	000
<i>Windward</i>	2	6/8	53.5°N	160.5°W	1	231	232	100R	356°	10°	40°	266°
	5	6/15	55°N	156°W	1	34	35	97R	343°	75°	17°	252°
	6	6/16	54.5°N	155°W	12	33	45	73R	334°	25°	15°	244°
	7	6/17	53.5°N	155°W	5	67	72	93R	349°	0°	0°	259°
	8	6/18	53°N	155°W	2	65	67	97R	293°	65°	41°	203°
	10	6/20	51.5°N	155°W	74	1	75	99L	205°	40°	40°	295°
	12	6/22	50°N	156.5°W	0	37	37	100R	090°	0°	15°	000
	13	6/25	51.5°N	158°W	6	17	23	74R	301°	20°	11°	211°
	14	6/27	53°N	158°W	124	17	141	88L	266°	25°	2°	356°
	16	6/29	54.5°N	158°W	5	27	32	84R	285°	10°	40°	195°
	18	7/10	53.5°N	163°W	2	61	63	97R	349°	40°	21°	259°
	22	7/14	51.5°N	162.5°W	13	20	33	61R	109°	10°	39°	019°
	24	7/25	50.5°N	160°W	62	13	75	83L	231°	40°	81°	321°
	25	7/26	51.5°N	160°W	27	4	31	87L	188°	35°	42°	278°
	26	7/27	52°N	160°W	19	4	23	83L	205°	20°	5°	295°
	29	8/17	55.5°N	155°W	5	23	28	82R	175°	30°	20°	085°
	30	8/21	54.5°N	155°W	25	4	29	86L	204°	75°	24°	294°
	31	8/22	53.5°N	155°W	20	5	25	80L	261°	50°	66°	351°
	32	8/23	52.5°N	155°W	124	7	131	95L	272°	5°	7°	002°
<i>Bertha Ann</i>	2	8/13	59°N	150°W	17	5	22	77L	005°	90°	40°	095°
	4	8/18	56°N	150°W	49	193	242	80R	212°	0°	10°	122°
	7	8/22	52°N	150°W	20	9	29	69L	232°	20°	15°	322°
	12	8/27	52°N	147°W	25	8	33	76L	243°	0°	40°	333°
	13	8/29	53°N	147°W	15	8	23	65L	204°	60°	1°	294°
	14	8/30	54.5°N	147°W	6	22	28	79R	220°	50°	39°	130°
	15	8/31	55°N	147°W	209	56	265	79L	224°	70°	20°	314°
	16	9/1	56°N	147°W	31	12	43	72L	269°	50°	19°	359°
	21	9/14	58°N	144°W	12	29	41	71R	350°	80°	37°	260°

TABLE 3. Assignment of direction of movement to pink salmon caught in gillnets, 1961.

Vessel	Set number	Haul date	Location		Number left	Number right	Total	Percent direction	Haul direction	Individual net variation	Net swing	Predominant direction of travel
			Latitude	Longitude								
<i>Marine View</i>	10	6/18	53.5°N	173.5°W	49	13	62	79L	225°	30°	13°	315°
	13	6/21	56°N	180°	4	36	40	90R	034°	10°	27°	304°
	14	6/23	57°N	180°	80	9	89	90L	240°	35°	8°	330°
	15	6/25	59°N	180°	95	13	108	88L	220°	40°	11°	310°
	16	6/27	55°N	175°E	101	8	109	93L	191°	30°	8°	281°
	17	6/28	54°N	175°E	146	35	181	81L	197°	10°	13°	287°
	19	7/11	51°N	177.5°W	7	15	22	68R	113°	20°	60°	023°
	20	7/12	50.5°N	177.5°W	4	31	35	89R	059°	90°	6°	329°
<i>Windward</i>	8	6/18	53°N	155°W	3	21	24	87R	293°	65°	41°	203°
	10	6/20	51.5°N	155°W	106	3	109	97L	205°	40°	40°	295°
	12	6/22	50°N	156.5°W	4	58	62	94R	090°	0°	15°	000
	14	6/27	53°N	158°W	85	2	87	98L	266°	25°	2°	356°
	19	7/11	53°N	162.5°W	55	21	76	72L	252°	15°	48°	342°
	20	7/12	52.5°N	162.5°W	54	29	83	65L	347°	70°	52°	077°
	26	7/27	52°N	160°W	34	0	34	100L	205°	20°	5°	295°

usable sets¹ provided us with data from 34 sets for sockeye salmon, 45 sets for chum salmon and 15 sets for pink salmon which were acceptable. These sets are itemized in Tables 1–3. Generally, the summer season proved the most successful for the collection of direction data, due mainly to better weather in the study area. Late in the summer catches fell off in the Gulf of Alaska and resulted in otherwise usable sets being rejected for lack of an adequate sample. The offshore stations were the most productive in terms of direction data as they were free of the net tangling currents found near the mainland and island chain.

Data from the usable sets are portrayed for species and season (spring—May and June, summer—July, August and September) in Tables 1 through 3 and in Figures 2 through 6 where the larger catches are shown with heavy, full arrows and the smaller catches with light, half arrows. Results of pink salmon analyses are grouped for both seasons because the catch contained only maturing fish.

SOCKEYE SALMON

Spring. As shown in Figure 2, a general westward movement of primarily mature fish was suggested in the western Gulf of Alaska, south of the Alaska Peninsula to about 200 miles offshore. One catch of

immature sockeye farther south at 51°30'N., 155°W. indicates a northwesterly movement. In the eastern Bering Sea, a very definite eastward movement is shown, again mature and very likely Bristol Bay fish. Three of four sets in the central and western Bering Sea indicate a westward movement, the fourth set in this area shows a southeasterly movement.

Summer. In Figure 3, the two sets in the central Gulf of Alaska show a northwesterly movement of sockeye salmon. A westward movement of primarily immature sockeye is shown along the south side of the eastern and western Aleutian Chain and a northerly movement south of the center of the Chain. It appears that, during summer, the immature sockeye move up from the south until they encounter the

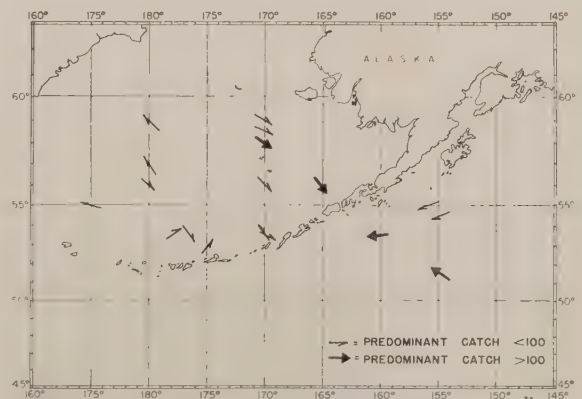


FIGURE 2. Predominant direction of travel of sockeye salmon as indicated by surface gillnet catches, May and June 1961.

¹ Elimination of sets due to:

	Criteria 1, 2, 3, 5	Criterion 4
Sockeye	81	11
Chum	75	6
Pink	111	0

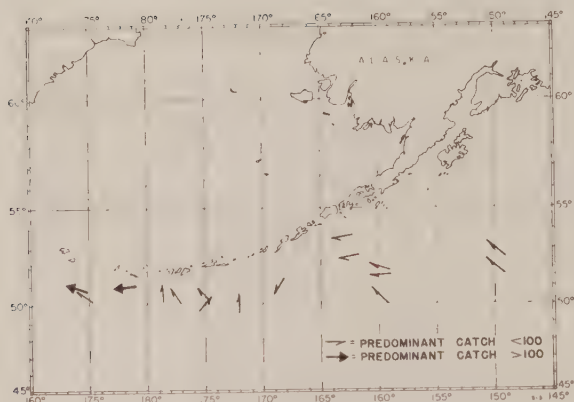


FIGURE 3. Predominant direction of travel of sockeye salmon as indicated by surface gillnet catches, July, August and September 1961.

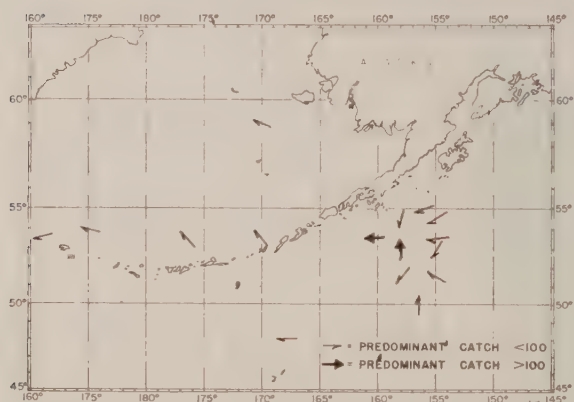


FIGURE 4. Predominant direction of travel of chum salmon as indicated by surface gillnet catches, May and June 1961.

Aleutian shelf and then turn westward to follow the Chain. There was no sampling in the Bering Sea during the summer season.

CHUM SALMON

Spring. Except for the western Gulf of Alaska, there are few usable sets during this period for chum salmon, but a northwestward movement is indicated in the eastern Bering Sea (Fig. 4). In the western half of the Bering Sea, two sets show a westward movement. In the western Gulf of Alaska, seven of ten sets show a general westerly movement, as does the single set in the eastern North Pacific Ocean.

Summer. There appears to be a northward movement in the North Pacific up to the central Aleutian Chain and a westward movement along the Chain farther to the west (Fig. 5), similar to the sockeye

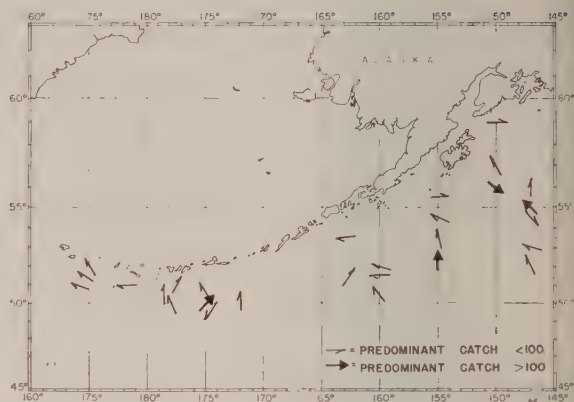


FIGURE 5. Predominant direction of travel of chum salmon as indicated by surface gillnet catches, July, August and September 1961.

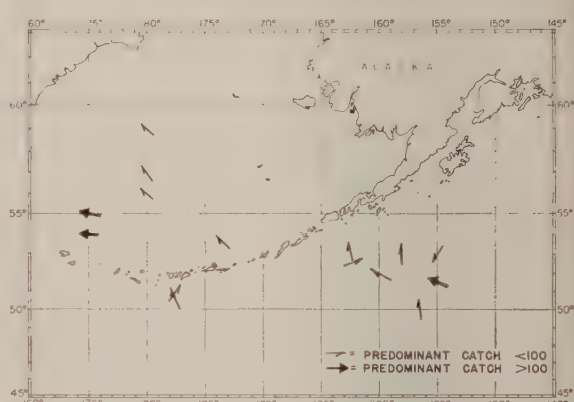


FIGURE 6. Predominant direction of travel of pink salmon as indicated by surface gillnet catches, May, June and July 1961.

salmon pattern for this season. The western Gulf of Alaska shows a northerly and westerly direction of travel; movement in the central Gulf area is confusing with northerly, easterly, westerly and southerly directions in adjacent sets. However, the southernmost sets in the Gulf show a northerly movement as noted in the central Aleutian area.

PINK SALMON

Pink salmon direction results are not portrayed for separate seasons as the fish which are taken by the sampling gear are all mature, one-winter-in-ocean fish and few are caught after July.

Data from the central and western Bering Sea indicate a primarily westward movement of pink salmon (Fig. 6). Two sets south of the central Aleutians show northerly travel. In the western Gulf of

Alaska, the direction is basically north and west, but one set shows a southerly movement and another an easterly movement.

COMPARISON BETWEEN GILLNET AND PURSE SEINE CATCHES

The Fisheries Research Institute of the University of Washington, under contract to the Bureau of Commercial Fisheries, has conducted a salmon tagging study in the Aleutian and Gulf of Alaska areas during the period covered by this report. Hartt (1962) has a complete description of methods and equipment. Four vessels, using salmon purse seines to collect samples for tagging, fished during the spring and summer months. F.R.I. records (unpublished data) show the direction the seine was held open, i.e., the direction from which fish could enter the net, for each set along with the catch for the particular set. When two or more sets were made in the same loca-

tion on the same day and held open in different directions, an indication of direction of travel of the salmon is shown by comparing the catches. If a set open east takes twice as many fish as one open west in the same area and time, then we assume the majority of the fish caught are moving in a westerly direction.

In interpreting the purse seine catches, the following criteria were applied to single out usable series of sets: (1) two or more sets in the same day; (2) sets in one day within ten miles of each other; (3) at least one of the sets in a day open in a different direction from the others; (4) at least 20 fish of a species in the combined sets of one day; and (5) consistency, in terms of largest or smallest number of fish, in the catches of sets open in the same direction. Of the 347 purse seine sets made during 1961 the majority were at times or in areas removed from the gillnet operations and will not be included here.

TABLE 4. Assignment of sockeye salmon direction of travel from purse seine catches, 1961.

Vessel	Set number	Date	Location		Direction open	Catch	Predominant direction of travel	Season
			Latitude	Longitude				
<i>Commander</i>	17	6/17	52°52'N	168°32'W	East	99	West	Spring
	18				West	0		
	19				East	380		
<i>Commander</i>	55	7/26	51°23'N	176°50'W	East	68	West	Summer
	56				West	0		
	57				East	51		
<i>Commander</i>	60	8/7	51°30'N	177°30'E	Southeast	127	Northwest	Summer
	61				Northeast	9		
	62				Southeast	119		
<i>Commander</i>	64	8/16	51°30'N	177°30'E	East	40	Northwest	Summer
	65				West	27		
	66				Southeast	105		

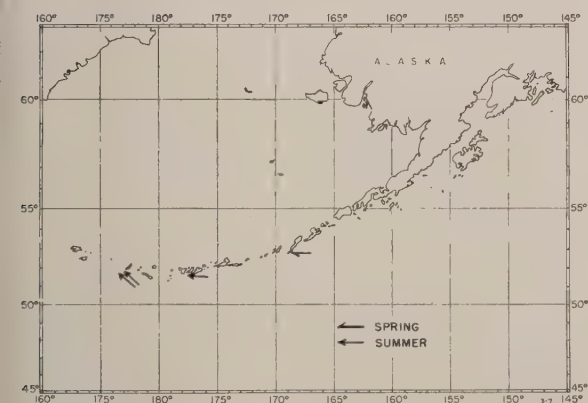


FIGURE 7. Predominant direction of travel of sockeye salmon as indicated by purse seine catches, 1961.

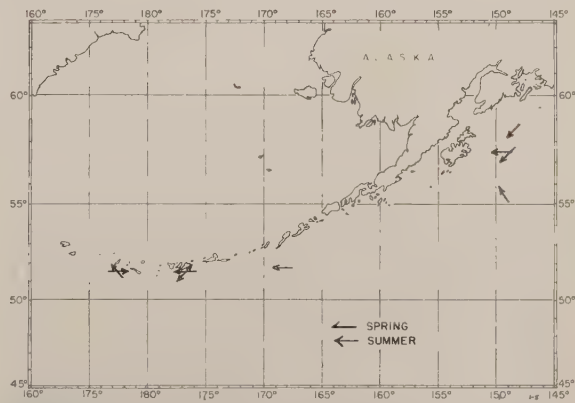


FIGURE 8. Predominant direction of travel of chum salmon as indicated by purse seine catches, 1961.

TABLE 5. Assignment of chum salmon direction of travel from purse seine catches, 1961.

Vessel	Set number	Date	Location		Direction	open	Catch	Predominant direction of travel	Season
			Latitude	Longitude					
<i>Storm</i>	50	7/13	57°30'N	149°30'W	West		4		
	51				East		29	West	Summer
<i>Renown</i>	30	7/17	51°36'N	176°30'W	Northeast		12		
	31				Northeast		20	Northeast	Summer
	32	7/21	51°46'N	168°38'W	Southwest		52		
	36				East		81		
<i>Storm</i>	37				West		4	West	
	57	7/22	57°20'N	149°00'W	Northwest		5		
	58				East		30	Southwest	Summer
	50				Northeast		50		
	60	7/23	58°40'N	148°20'W	East		108		
	61				Northeast		144	Southwest	Summer
	62	7/26	55°26'N	149°42'W	West		20		
	67				Northeast		13		
	68				Northeast		17		
	69				Southeast		25	Northwest	Summer
	70				West		4		
<i>Commander</i>	55	7/26	51°23'N	176°50'W	East		81	West	
	56				West		0		Summer
	57				East		27		
	60	8/7	51°30'N	177°30'E	Southeast		9		
	61				Northeast		3	Northwest	Summer
	62	8/16	51°30'N	177°30'E	Southeast		16		
	64				East		12		
	65				West		44	East	Summer
	66				Southeast		5		
<i>Renown</i>	48	8/22	51°20'N	176°25'W	Northeast		30	Southwest	Summer
	49				West		0		
	50				Southeast		1		

TABLE 6. Assignment of direction of travel to pink salmon caught by purse seine, 1961.

Vessel	Set number	Date	Location		Direction	open	Catch	Predominant direction of travel
			Latitude	Longitude				
<i>Commander</i>	17	6/17	52°52'N	168°32'W	East		15	West
	18				West		0	
	19				East		61	
<i>Storm</i>	50	7/13	57°30'N	149°30'W	West		10	
	51				East		28	West
	67	7/26	55°26'N	149°42'W	Northeast		3	
	68				Northeast		4	
	69				Southeast		23	Northwest
	70				West		2	

In accordance with the above limitations, four acceptable purse seine direction assignments fall within the areas in which we have sockeye salmon gillnet data (Table 4). This gives a very limited overlap, but the three summer observations in the western Aleutians are in agreement with the direction indicated by our gillnet catches—westward movement

of immatures along the Aleutian Chain (Fig. 7). The single spring direction assignment in the eastern North Pacific Ocean also shows a westward movement.

Usable direction data for chum salmon in the high seas areas are from 10 days (Table 5) and may be

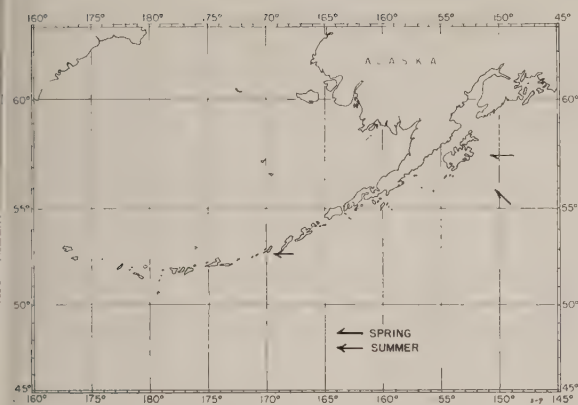


FIGURE 9. Predominant direction of travel of pink salmon as indicated by purse seine catches, 1961.

used to supplement the gillnet data, although considerable variation in the results is noted. In the summer, westward movement along the south side of the Aleutian Chain is evident in three series of sets (Fig. 8), as is true with the gillnet samples, but three other series depart from the pattern established by the gillnet data, showing easterly, northeasterly and southwesterly directions in this area. These three observations may have resulted from a local variation in migration caused by feeding conditions, currents, or perhaps, the capture of chum salmon from different stocks. In the western Gulf of Alaska, generally westward travel of mature chums is shown; gillnet results in this region were extremely variable for chum salmon.

Only three usable series of purse seine sets for pink salmon are in the area of high seas gillnet sampling; one in the eastern Aleutian Islands and two in the western Gulf of Alaska (Table 6). The lone sample in the Aleutian area (Fig. 9) shows a westward movement corresponding to the gillnet data in the Bering Sea. There were no gillnet samples of pink salmon in the Gulf of Alaska for comparison.

In summary then, there is no large contradiction between the available direction information from high seas purse seine and gillnet catches in the relatively small areas where there are comparable data.

COMPARISON WITH PAST YEARS

In comparison with the earlier work on salmon direction, there are some local differences that are readily apparent. For sockeye salmon, Johnsen (1964) shows a slight west and northwest trend in the south-central Bering Sea in the spring of 1959 and 1960 which was not noticed in 1961. During the

summers of 1959 and 1960 he also found a considerable variation in the chum salmon directions south of the central Aleutians, with south, southwest, west, northwest, north and southeast movements in contrast to the predominant assignment of northerly directions in 1961.

Hartt (1962), reporting the direction of movement of salmon as measured by purse seine catches for 1956 through 1958, found much the same direction pattern in the Aleutian area as our gillnet samples have shown and further describes in detail the movements inshore and through the island passes not accessible to gillnet sampling.

In general, with relatively minor variations, the 1961 gillnet direction results are similar to the direction results of gillnetting and purse seining during the period 1956 through 1960.

CONCLUSIONS

During the spring, surface gillnet catches suggest that most of the sockeye salmon are eastbound in the eastern half of the Bering Sea (east of 180°) and westbound in the central Bering Sea; westbound sockeye predominate in the western Gulf of Alaska. In summer, the catches suggest that sockeye salmon move northward in the North Pacific Ocean until they near the Aleutian Chain, where a general westward movement occurs.

Chum salmon in the spring are quite variable in their movements, but a general westward trend is seen in the Bering Sea data and western Gulf of Alaska. During the summer season, the chum movement is similar to that of the sockeye salmon in the North Pacific—northward to the Aleutian Chain, then westward. In the Gulf of Alaska, there is a northward movement below 53°N., and east and west movements further to the north.

There are few usable pink salmon data, but these show a northward movement south of the central Aleutians and a general westward movement in the Bering Sea; assigned directions in the western Gulf of Alaska are variable but indicate a general westward movement.

The similarity of results shown for 1956 through 1958 (Hartt, 1962), 1959 and 1960 (Johnsen, 1964) and for 1961 in this report suggests that the general pattern of spring and summer high seas salmon migration in the Aleutian area has been as described above.

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**Some Epipelagic Fishes of the North Pacific Ocean,
Bering Sea, and Gulf of Alaska**

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Some Epipelagic Fishes of the North Pacific Ocean, Bering Sea, and Gulf of Alaska

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ABSTRACT

In the course of salmon gill-netting operations in the North Pacific Ocean, Bering Sea, and Gulf of Alaska over a 7-year period, 37 species of fishes other than salmon have been captured incidentally. The catches of such species are listed by area and their relative abundance is calculated. Compared to salmon in the same localities, the incidental species are taken in small numbers and over limited ranges.

Three species have heretofore been considered quite rare, another has been seen previously only in the South Pacific, and one may represent a new species. Several fishes show seasonal variations in distribution, possibly related to a preference for warmer water.

INTRODUCTION

Since 1955, the U. S. Bureau of Commercial Fisheries, as one of the research agencies of the International North Pacific Fisheries Commission, has conducted a high seas salmon (*Oncorhynchus* sp.) sampling program in the Bering Sea, North Pacific Ocean, and Gulf of Alaska. Fishing operations through 1961 consisted of nighttime gill-net sets from bureau-owned or chartered vessels during the spring and summer months.

Although our sampling was designed to capture Pacific salmon, it has also provided a valuable insight into the distribution and relative abundance of other fishes from the epipelagic zone. In addition to salmon, fishery biologists on board the research vessels have identified 37 species, some of which are rarely seen.

Neave and Hanavan (1960) reported, in some detail, the seasonal distribution of pomfret, blue shark, mackerel (salmon) shark, jack mackerel, albacore, and the salmonids in the Gulf of Alaska. Hitz and French¹ analyzed the annual and seasonal distribution and abundance of pomfret, and Abe (1952) reported on specimens of the daggertooth and pomfret in the northwestern Pacific. Clemens and Wilby (1961) provided an excellent source of taxonomic and distributional data for the known species of the North Pacific Ocean and Gulf of Alaska. Analyses of salmon

abundance and distribution are presented in the Annual Reports of the International North Pacific Fisheries Commission for the years 1955 through 1961. These reports also contain the positions of individual gill-net stations from which the catch data in this report are collected.

This paper deals with the identification, distribution, and gross measures of relative abundance of the fishes taken by the bureau between 1955 and 1961 incidental to the salmon catches.

METHODS AND MATERIALS

The nylon gill-net strings were composed of individual shackles, each 50 fathoms in length, 4 fathoms in depth, and of various mesh sizes ranging from 2 to 5¼ inches (stretched measure). The length of the net string and proportions of different mesh sizes have varied within and between years, the trend being toward longer net strings (up to 40 shackles) and a higher proportion of the middle mesh sizes (3¼ and 4½ inches). The gill nets regularly capture all sizes of salmon between 25 and 70 centimeters in length; however, this fact does not preclude the catch of either larger or smaller fish with various degrees of efficiency depending on body shape, fin structure, or behavior. The catch of Atka mackerel under 14 centimeters (5½ inches) and salmon sharks over 182 centimeters (6 feet) in length attests that gill nets are capable of taking fish over a size range greater than that for which they are designed.

¹ Hitz, Charles R., and Robert French. (1963) U. S. Bureau of Commercial Fisheries, Biological Laboratory, Seattle, Washington. Manuscript.

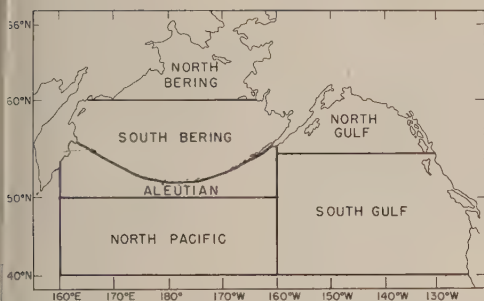


FIGURE 1.—Areas of high seas fishing effort.

Normal fishing operations consisted of setting the net string at dusk, allowing it to soak for about 12 hours, and hauling it aboard shortly after dawn. As the nets came in the salmon catch was recorded for each net, but only the total numbers of the other species present were recorded with no attempt to count them by mesh size. When possible, unusual specimens were frozen or otherwise preserved for retention in the Seattle Biological Laboratory's fish collection. Very often adverse weather conditions or a heavy salmon catch necessitated the recording and discard of incidental species after only a cursory examination. Errors due to misidentification or the use of nonspecific common names in the field records have undoubtedly occurred.

ANALYTICAL PROCEDURES

In order to portray the occurrence of the epipelagic fishes of the region in terms of geographical units, arbitrary areas are designated in the following manner (Figure 1):

North Bering—north of 60° N.

South Bering—between 60° N and the Aleutian Islands.

Aleutian—between the Aleutian Islands and 50° N, and between 160° E and 160° W.

North Pacific—between 40° N and 50° N, and between 160° E and 160° W.

North Gulf—north of 54° N and east of 160° W.

South Gulf—between 40° N and 54° N, and east of 160° W.

Because of the very small catches of many species, the data for all months and years

TABLE 1.—Total fishing effort (number of 50-fathom shackles) per area

Year	North Bering	South Bering	Aleutian	North Pacific	North Gulf	South Gulf	Total
1955	0	0	246	360	730	220	1,556
1956	36	792	345	345	378	1,367	3,263
1957	0	1,281	803	0	72	192	2,348
1958	0	1,028	527	168	46	94	1,863
1959	36	840	1,032	432	69	252	2,661
1960	0	852	1,692	288	36	72	2,940
1961	0	1,075	1,556	320	1,045	681	4,677
Total	72	5,868	6,201	1,913	2,376	2,878	19,308
No. sets	3	232	245	76	94	113	763

have been combined. Differences due to season or year are noted in the text.

Determinations of catch per unit of effort are limited to the total catch of each species in relation to the total number of shackles fished by area because of the lack of catch data by mesh size. The effect on the catch of the various species due to the differing proportions of mesh sizes is not known but it is believed that the area-to-area comparisons are not severely biased.

Relative abundance is portrayed in terms of catch per 100 shackles of gill net with total effort expended in the six areas shown in Table 1. To visualize better the significance of the catch-per-100-shackles statistic, this basic unit of effort consists of a surface gill-net string of mesh sizes ranging from 2 to 5¼ inches, with a length of 5,000 fathoms (5 miles).

Fishing stations were well scattered, both in time and space, throughout each area except the North Bering. Therefore, the calculation of percentage of sets in an area in which a particular species was captured provides a basis for determining species dispersal; the higher the percentage, the more widely distributed is the species in space and time. This determination, however, is valid only for the species taken in some number. Where only two or three fish were caught, the index of dispersal must be small even if the fish were widely and evenly spaced.

RESULTS

Table 2 lists salmon, the species incidentally caught, and the total numbers of each taken from 1955 through 1961. Precise catch information for those species observed very rarely (fewer than 5 specimens) is shown in

TABLE 2.—Numbers of specimens of each species taken on the high seas of the Bering Sea, North Pacific Ocean, and Gulf of Alaska, 1955-61

Common name	Family name	Scientific name	Number taken
Albacore	Scombridae	<i>Thunnus alalunga</i>	299
Arrowtooth flounder ¹	Pleuronectidae	<i>Atheresthes stomias</i>	1
Atka mackerel	Hexagrammidae	<i>Pleuragrammus monoptyerygius</i>	7,322
Basking shark	Lamnidae	<i>Cetorhinus maximus</i>	1
Bigscale pomfret	Bramidae	<i>Taractes</i> sp.	1
Blue shark	Carcharhinidae	<i>Prionace glauca</i>	877
Boarfish	Histiophoridae	<i>Pseudopentaceros richardsoni</i>	9
Coster dory	Zeidae	<i>Alloctytus verrucosus</i>	1
Daggertooth	Anotopteridae	<i>Anotopterus pharao</i>	31
Dolly Varden	Salmonidae	<i>Salvelinus malma</i>	60
English (lemon) sole ¹	Pleuronectidae	<i>Parophrys vetulus</i>	2
Eulachon	Osmeridae	<i>Thaleichthys pacificus</i>	1
Jack mackerel	Carangidae	<i>Trachurus symmetricus</i>	1,295
Opah	Lampridae	<i>Lampris regius</i>	1
Pacific hake	Gadidae	<i>Merluccius productus</i>	23
Pacific herring	Clupeidae	<i>Clupea harengus pallasi</i>	4,649
Pacific lamprey	Petromyzontidae	<i>Lampetra tridentata</i>	5
Pacific lancetfish	Alepisauridae	<i>Alepisaurus richardsoni</i>	14
Pacific sandfish	Trichodontidae	<i>Trichodon trichodon</i>	3
Pacific saury	Scombersocidae	<i>Cololabis saira</i>	2
Pomfret	Bramidae	<i>Brama rayi</i>	4,425
Ragfish	Icesteidae	<i>Icesteus aenigmaticus</i>	9
Rockfish	Scorpaenidae	<i>Sebastes</i> sp.	2
Sablefish	Anoplopomatidae	<i>Anoplopoma fimbria</i>	93
Salmon shark	Lamnidae	<i>Lamna ditropis</i>	172
Sculpin ¹	Cottidae	Unknown	1
Sea poacher ¹	Agonidae	Unknown	6
Sixgill shark	Hexanchidae	<i>Hexanchus griseum</i>	1
Skiffish	Anoplopomatidae	<i>Erilepis zonifer</i>	145
Smalleye squaretail	Tetragonuridae	<i>Tetragonurus cuvieri</i>	247
Spiny dogfish	Squalidae	<i>Squalus acanthias</i>	105
Steelhead (rainbow) trout	Salmonidae	<i>Salmo gairdneri</i>	602
Threespine stickleback	Gasterosteidae	<i>Gasterosteus aculeatus</i>	38
Walleye pollock	Gadidae	<i>Theragra chalcogrammus</i>	145
Wolf-eel	Anarchichadidae	<i>Anarrhichthys ocellatus</i>	2
Yellowfin sole ¹	Pleuronectidae	<i>Limanda aspera</i>	12
Yellowfin tuna	Scombridae	<i>Thunnus albacares</i>	1
Chinook (king) salmon	Salmonidae	<i>Oncorhynchus tshawytscha</i>	390
Chum salmon	Salmonidae	<i>O. keta</i>	32,637
Coho (silver) salmon	Salmonidae	<i>O. kisutch</i>	2,031
Pink salmon	Salmonidae	<i>O. gorbuscha</i>	15,026
Sockeye (red) salmon	Salmonidae	<i>O. nerka</i>	20,371

¹ Benthic forms captured in sets made in shallow water.

Table 3. The catch per unit of effort and the percentage of sets which took the various species of fishes are given in Table 4.

The column labeled "Abundance" is an arbitrary measure of the fishes' availability to

the salmon gill nets; the effectiveness of the nets varies for the different species. Therefore, relative-abundance comparisons between species must be limited to those of comparable size and body shape.

The most striking feature of these catches is, with the exception of six species, the apparent low abundance of the epipelagic fish in relation to salmon catches in this region. Over the entire region, salmon catches usually range from one to ten fish *per shackle*. The six species classed as "abundant" (blue shark, pomfret, jack mackerel, Atka mackerel, albacore, and herring) were found in quantity in only two or three areas. No species, other than salmon, was found throughout the region in any sizable numbers.

Yellowfin sole, English sole, arrowtooth flounder, sea poacher, and sculpin are benthic forms and were taken in sets made in shallow water; they are included only for completeness.

TABLE 3.—Date and position of capture of those species in which fewer than five specimens have been observed

Species	Date captured	Position
Arrowtooth flounder ¹	July 21, 1958	53°07' N, 176°55' E
Basking shark	August 19, 1958	50°00' N, 165°00' W
Bigscale pomfret	July 31, 1956	49°59' N, 160°03' W
Coster dory	July 23, 1956	50°00' N, 150°00' W
English sole ¹ (2)	June 18, 1961	59°14' N, 169°58' W
Eulachon	August 15, 1957	50°00' N, 165°00' W
Opah	August 15, 1955	48°00' N, 175°00' W
Pacific sandfish (3)	August 15, 1957	55°00' N, 165°00' W
Pacific saury	August 8, 1957	50°00' N, 175°00' E
Pacific saury	August 19, 1957	51°30' N, 175°00' E
Rockfish	July 12, 1956	59°00' N, 140°00' W
Rockfish	May 18, 1960	52°50' N, 167°06' W
Sculpin ¹	August 21, 1961	55°00' N, 157°30' W
Sixgill shark	September 9, 1956	53°00' N, 165°00' W
Wolf-eel (2)	August 14, 1956	56°04' N, 164°56' W
Yellowfin tuna	August 24, 1961	50°00' N, 150°02' W

¹ Benthic forms captured in sets made in shallow water.

TABLE 4.—Catch per 100 shackles and percentage of sets which took various epipelagic species, by area, 1955-61

Species	North Bering		South Bering		Aleutian		Pacific		North Gulf		South Gulf		Range ²	Abundance ³
	c/100 shack-les	% ¹ sets	c/100 shack-les	% ¹ sets	c/100 shack-les	% ¹ sets	c/100 shack-les	% ¹ sets	c/100 shack-les	% ¹ sets	c/100 shack-les	% ¹ sets		
Albacore	0		0		0		12.9	25	0		1.7	12	2	Abundant
Arrowtooth flounder	0	<0.1	<1		0		0		0		0		1	Rare
Atka mackerel	0	31.9	30		83.2	13	0		6.9	15	2.8	4	4	Abundant
Masking shark	0	0			<0.1	<1	0		0		0		1	Rare
Bigscale pomfret	0	0			0		0		0		<0.1	<1	1	"
Blue shark	0	0			0		23.1	39	0.5	6	14.3	44	3	Abundant
Boarfish	0	0			0		0		<0.1	1	0.3	5	2	Rare
Coster dory	0	0			0		0		0		<0.1	1	1	"
Daggertooth	0	0			0.4	12	0.2	3	<0.1	1	<0.1	1	4	"
Dogfish shark	0	0.1	3		0.5	11	0.3	5	2.2	6	0.3	6	5	Common
Dolly Varden	8.3	33	0.9	5	0		0		0		0		2	"
English (lemon) sole	0	<0.1	<1		0		0		0		0		1	Rare
Jackchion	0	0			0		0		0		<0.1	1	1	"
Lake	0	0.3	3		0		0		0.1	1	<0.1	1	3	"
Herring	31.9	67	78.6	5	0		0		<0.1	1	0		3	Abundant
Jack mackerel ⁴	0	0			0		0		10.9	17	35.2	30	2	"
Wanctfish	0	<0.1	1		0.2	2	<0.1	1	0		<0.1	1	4	Rare
Pomprey	0	0			0.1	2	0		0		0		1	"
Pah	0	0			0		<0.1	1	0		0		1	"
Pomfret	0	0			8.7	11	61.8	62	38.6	43	60.2	64	4	Abundant
Ragfish	0	<0.1	<1		<0.1	1	0		0.2	3	<0.1	1	4	Rare
Sablefish	0	0.1	<1		<0.1	<1	0		3.4	12	0.1	1	4	Common
Sandfish	0	0.1	<1		0		0		0		0		1	Rare
Saury	0	0			<0.1	1	0		0		0		1	"
Sculpin	0	0			0		0		<0.1	1	0		1	"
Seapoacher	0	0.1	1		0		0		0		0		1	"
Sebastodes sp.	0	0			<0.1	<1	0		<0.1	1	0		2	"
Sixgill shark	0	0			<0.1	<1	0		0		0		1	"
Skiffish	0	0			0.6	4	1.8	16	0.3	4	2.2	30	4	Common
Steelhead trout	0	<0.1	<1		4.3	26	2.1	17	5.4	54	5.6	48	5	"
Squairetail	0	0			<0.1	<1	9.4	11	0		2.1	5	3	"
Threespine stickleback	0	0			<0.1	<1	0		1.6	3	0		2	"
Walleye pollock	0	2.5	9		0		0		0		0		1	"
Wolf-eel	0	<0.1	<1		0		0		0		0		1	Rare
Yellowfin tuna	0	0			0		0		0		<0.1	1	1	"
Yellowfin sole	5.6	33	0.1	3	0		0		0		0		2	Common
No. sets	3		232		245		76		94		113			
No. shackles	72		5,868		6,201		1,913		2,376		2,878			

¹ Percentage of sets in which each species was taken, regardless of numbers caught.² Number of areas in which taken.³ "Rare" indicates c/100 shackles < 1.0 in any area.

"Common" indicates c/100 shackles between 1.0 ~ 10.0 in any area.

"Abundant" indicates c/100 shackles > 10.0 in any area.

⁴ May include some catches of Pacific mackerel (*Scomber japonicus*).TABLE 5.—Differences in abundance in spring and summer¹

Species	Area	Abundance greatest in
Albacore	North Pacific	Summer
	South Gulf	Summer
Atka mackerel	Aleutian	Summer
	North Gulf	Summer
	South Gulf	Summer
Blue shark	North Pacific	Summer
	South Gulf	Summer
Dolly Varden	North Bering	Spring
Dogfish	North Gulf	Summer
Herring	North Bering	Spring
	South Bering	Spring
Jack mackerel	North Gulf	Summer
	South Gulf	Summer
Pomfret	Aleutian	Summer
	North Pacific	Summer
	North Gulf	Summer
	South Gulf	Summer
Sablefish	North Gulf	Summer
Skiffish	North Pacific	Summer
	South Gulf	Summer
Squairetail	North Pacific	Summer
Steelhead trout	Aleutian	Summer
	North Pacific	Summer
	North Gulf	Summer
Walleye pollock	South Bering	Spring

¹ Spring—May, June. Summer—July, August, September.

Seasonal differences in abundance (within areas) were noticeable in thirteen species as shown in Table 5.

DISCUSSION

Of the species encountered during the 7 years of fishing effort, the daggertooth, skiffish, and boarfish had been considered to be quite rare, at least in waters of this region, with only a few previously reported specimens of each (Clemens and Wilby, 1961). The big-scale pomfret taken has not been identified beyond genus and may represent an unknown species. One other species, the coster dory, had been known only in the vicinity of South Africa and New Zealand, and this specimen apparently represents the first instance of its capture in the North Pacific (Welandar, John-

TABLE 6.—Surface temperature ranges (°C.) in the North Pacific Ocean, Bering Sea, and Gulf of Alaska during the spring and summer

	Spring ¹	Summer ¹
North Bering	1.2–6.5	7.9
South Bering	0.5–9.5	4.6–11.5
Aleutian	3.6–7.0	5.8–13.8
North Pacific	3.1–12.9	9.9–19.1
North Gulf	4.0–4.9	9.1–14.1
South Gulf	5.3–10.9	9.4–17.2

¹ Spring—May and June. Summer—July, August, September.

sen, and Hajny, 1957; Clemens and Wilby, 1961).

In the presentation of the species which showed seasonal differences in abundance by area (Table 5) the greater abundance was noted in the summer (July, August, September) for all but four. This perhaps indicates a preference for the higher water temperatures during the summer. Surface temperature ranges are shown in Table 6. This point is further emphasized by Neave and Hanavan (1960) and in the results of some limited fishing effort in these same areas during the winters of 1962 and 1963, in which no species other than the salmonids and a few salmon sharks were caught.

In addition to the 37 species covered in this report, relatively large catches of Pacific mackerel (*Scomber japonicus*) were made during the late summer of 1962 in the South

Gulf and Aleutian areas. Also, large numbers of lanternfish (family Myctophidae) have been commonly recovered from the stomachs of gill-net caught salmon.

Finally, the regular capture of sockeye (*O. nerka*), chum (*O. keta*), pink (*O. gorbuscha*), coho (*O. kisutch*), and chinook salmon (*O. tshawytscha*) brings the total of species captured in the epipelagic strata of the Bering Sea, North Pacific Ocean, and Gulf of Alaska to 39 (excluding the five benthic species mentioned above).

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EFFECT OF DIRECTION OF SET AND DISTANCE BETWEEN NETS ON THE SALMON CATCH OF TWO GILLNETS

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Seattle, Washington, August 1963

ABSTRACT

As part of the Bureau of Commercial Fisheries continuing high salmon research, a series of five paired surface gillnet sets were fished in the eastern North Pacific Ocean during September 1962. At two of the stations, the nets were set at right angles to each other to determine the effect of direction of net lay on salmon catch. At the remaining three stations, the nets were set parallel but with distances of two, four and eight miles between them to measure changes in abundance over these distances. Statistical comparisons of salmon and incidental species catches indicated that (1) the lay of the net can influence the salmon and other catch and (2) salmon distribution is quite even with no noticeable change in abundance over the observed distances, although pomfret and Pacific mackerel abundance was very variable.

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INTRODUCTION

Under the auspices of the United States Section of the International North Pacific Fisheries Commission, research vessels of the Bureau of Commercial Fisheries have conducted a high seas salmon (*Oncorhynchus* spp.) sampling program in the North Pacific Ocean, Bering Sea and Gulf of Alaska since 1955. These vessels, using surface drift gillnets, provide data on salmon distribution, abundance and migration routes and collect whole fish samples for racial analysis in the laboratory.

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Use of these catch data assumes that the gillnet catches generally reflect the relative abundance of salmon in the areas sampled. This raises several questions regarding sources of variation in gillnet catches. These may include the efficiency of gillnets relative to the size of the salmon, behavioral characteristics of salmon, direction of set, variations between vessels and other sources. Fukuhara (MS 1961), in comparing salmon catches of two vessels fishing during a comparable time period in the Bering Sea, concluded there was no difference in the relative efficiency of the two vessels. His results in testing the effects of variation due to direction of set indicated significant differences in one year, 1959, but not in 1960.

This report presents the analysis of catch data obtained by two research vessels fishing (1) two parallel gillnet strings, two, four and eight miles apart, and (2) two adjacent gillnet strings set at right angles.

EXPERIMENTAL PROCEDURE

During the summer of 1962, the nearly identical, 176-foot research vessels MV *Bertha Ann* and MV *George B. Kelez* fished together in the eastern North Pacific Ocean at five stations along 157° W. (Fig. 1). The nets of the *Kelez* were set at right angles to the nets of the *Bertha Ann* during the first two sets. In the last three sets, the nets of the two vessels were set in

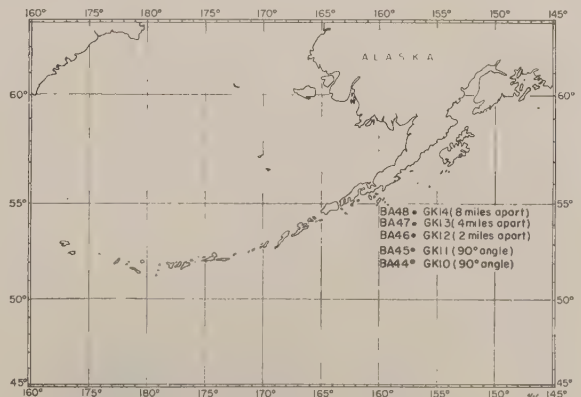


FIGURE 1. Location of paired set gillnet stations, 1962.

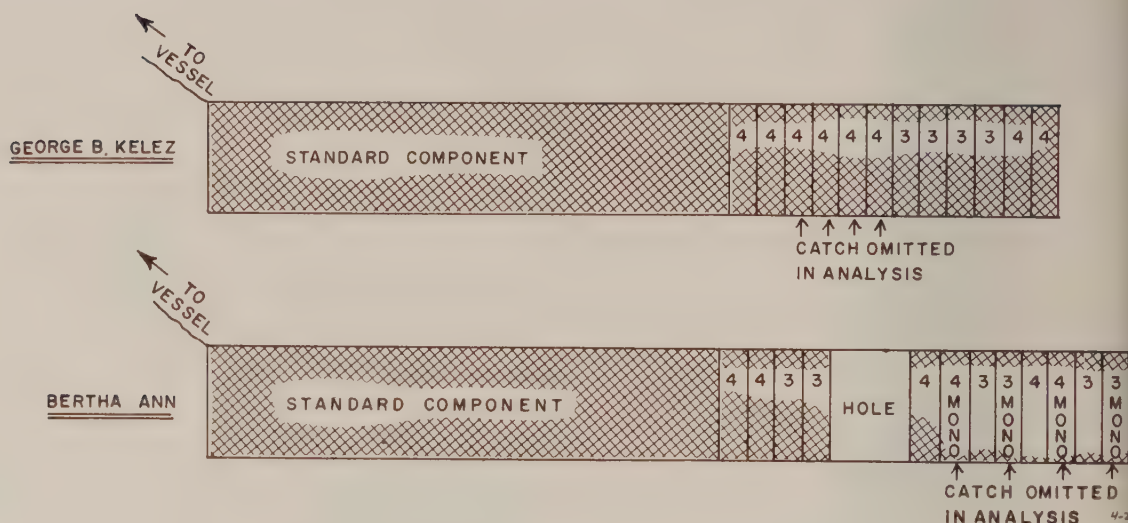


FIGURE 2. Gillnet string make-up used by research vessels during paired set experiment.

the same direction but with distances of two, four and eight miles between them.

The strings of both vessels consisted of an identical 24-net INPFC standard component plus 12 additional nets. The standard component is constructed of different mesh sizes in the following order: $4\frac{1}{2}$ -inch, $5\frac{1}{4}$ -inch, $4\frac{1}{2}$ -inch, $3\frac{1}{4}$ -inch, $4\frac{1}{2}$ -inch, $2\frac{1}{2}$ -inch (stretched measure), repeated four times. The additional 12 nets of the *Bertha Ann* string contained four $4\frac{1}{2}$ -inch, four $3\frac{1}{4}$ -inch, two $4\frac{1}{2}$ -inch monofilament and two $3\frac{1}{4}$ -inch monofilament nets. In the *Kelez* string, this section contained eight $4\frac{1}{2}$ -inch and four $3\frac{1}{4}$ -inch nets (Fig. 2).

The monofilament nets in the *Bertha Ann* string have been shown to be much more efficient than multifilament nets of like mesh size (Larkins, 1963); therefore, the catch of these four nets was eliminated from the *Bertha Ann* data for purposes of comparison. In order to present the catch data of the two strings in terms of equal effort, the catch of four $4\frac{1}{2}$ -inch nets of the *Kelez* string was also eliminated. These adjustments reduced both strings to a total of 32 multifilament nets, each consisting of the standard component plus four $4\frac{1}{2}$ -inch and four $3\frac{1}{4}$ -inch nets.

Larkins also indicated that the presence of monofilament nets can reduce the catch of adjacent $3\frac{1}{4}$ -inch multifilament nets. However, due possibly to the relatively small numbers of salmon taken in the $3\frac{1}{4}$ -inch nets, this effect was not found to be significant in the *Bertha Ann* catches made during this experiment.

Descriptions of individual nets, fishing method and shipboard routine were given by Powell and Petersen (1957) and Hanavan and Tanonaka (1959). Procedures for determining the direction of net lay have been described by Johnsen (1964) and Larkins (1964) and essentially consist of recording the heading of each net during the hauling process. The individual headings, and their average, delineate the shape and direction of the entire string.

As the nets were hauled aboard, the fish were tabulated by species, direction of entry into the net and the mesh size in which caught.

RESULTS

Catches of the two net strings for the five paired sets are shown in Tables 1 and 2. Through length frequency analysis, it was found that 94 percent of the younger age group of both sockeye (*O. nerka*) and chum (*O. keta*) salmon, 1-winter-at-sea and 2-year-olds, respectively, were taken in the $2\frac{1}{2}$ -inch and 3-inch nets (small mesh); 97 percent of the older age groups, 2-winter-at-sea sockeye and 3-year-old and older chum, were caught in the $4\frac{1}{2}$ -inch and $5\frac{1}{4}$ -inch nets (large mesh). Therefore, in the following analyses, the catch of the small mesh nets is considered to represent only the younger age groups and that of the large mesh nets only the older age groups.

In comparing the catches of the two strings in relation to the direction of set and distance between them, a necessary assumption is that the two strings fish

TABLE 1. Sockeye salmon catches in paired gillnet sets¹.

Vessel	Set	1-winter-at-sea			2-winters-at-sea			Type of set
		No. of fish	No. 2½" and 3½" mesh nets	Catch/small mesh net	No. of fish	No. 4½" and 5½" mesh nets	Catch/large mesh net	
<i>Bertha Ann</i>	44	15	12	1.25	47	20	2.35	90° angle
<i>George B. Kelez</i>	10	73	12	6.08	90	24	3.75	
<i>Bertha Ann</i>	45	12	12	1.00	22	20	1.10	90° angle
<i>George B. Kelez</i>	11	9	12	0.75	36	24	1.50	
<i>Bertha Ann</i>	46	14	12	1.17	13	20	0.65	2 miles
<i>George B. Kelez</i>	12	12	12	1.00	32	24	1.33	
<i>Bertha Ann</i>	47	14	12	1.17	3	20	0.15	4 miles
<i>George B. Kelez</i>	13	8	12	0.67	11	24	0.46	
<i>Bertha Ann</i>	48	4	12	0.33	3	20	0.15	8 miles
<i>George B. Kelez</i>	14	9	12	0.75	4	24	0.17	

¹ Excluding catch of *Bertha Ann* monofilament nets.TABLE 2. Chum salmon catches in paired gillnet sets¹.

Vessel	Set	2-year-old			3-year-old and older			Type of set
		No. of fish	No. 2½" and 3½" mesh nets	Catch/small mesh net	No. of fish	No. 4½" and 5½" mesh nets	Catch/large mesh net	
<i>Bertha Ann</i>	44	19	12	1.58	21	20	1.05	90° angle
<i>George B. Kelez</i>	10	28	12	2.33	36	24	1.50	
<i>Bertha Ann</i>	45	12	12	1.00	4	20	0.20	90° angle
<i>George B. Kelez</i>	11	18	12	1.50	20	24	0.83	
<i>Bertha Ann</i>	46	9	12	0.75	6	20	0.30	2 miles
<i>George B. Kelez</i>	12	5	12	0.42	13	24	0.54	
<i>Bertha Ann</i>	47	13	12	1.08	11	20	0.55	4 miles
<i>George B. Kelez</i>	13	15	12	1.25	7	24	0.29	
<i>Bertha Ann</i>	48	24	12	2.00	7	20	0.35	8 miles
<i>George B. Kelez</i>	14	12	12	1.00	4	24	0.17	

¹ Excluding catch of *Bertha Ann* monofilament nets.TABLE 3. Determination of relative efficiency of the two net strings¹.

Species and age	<i>Bertha Ann</i> set No. 46	<i>George B. Kelez</i> set No. 12	Total	Average	Chi-square	d. f.	Probability level
<i>Sockeye</i>							Percent
1-winter-at-sea	14	12	26	13.0	0.15	1	90-95
2-winters-at-sea	13	25	38	19.0	3.79	1	5-10
<i>Chum</i>							
2-year-old	9	5	14	7.0	1.14	1	20-30
3-year-old and older	6	13	19	9.5	2.58	1	10-20
Total	42	55	97	48.5	1.74	1	10-20
Pooled					7.66	4	10-20

¹ Excluding *Bertha Ann* monofilament nets and four 4½-inch nets of *George B. Kelez*.

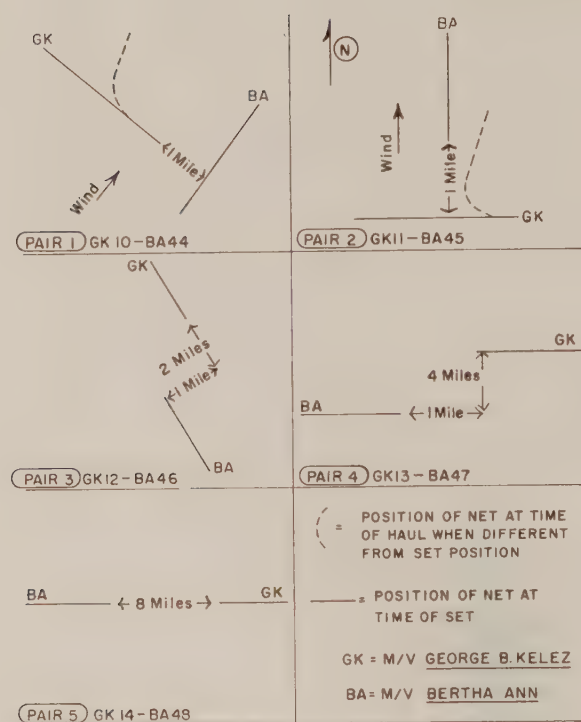


FIGURE 3. Position of net strings of MV *George B. Kelez* and MV *Bertha Ann* during paired set experiment.

with the same efficiency. In order to test this assumption, the pair of sets in which the strings were parallel and only two miles apart was used. Because the two-mile distance is only slightly longer than the net strings themselves, and because there was no noticeable change in the catch along the length of

either net string, it is believed that the differences in abundance, species composition and age class composition over that distance are no greater than those within each string. Therefore, the comparison of catches in those two net strings should serve as an adequate measure of whether or not one string is more efficient than the other.

Individual chi-square tests for the catches of 1-winter and 2-winter-at-sea sockeye salmon and 2-year-old and 3-year-old and older chum salmon in the two strings (Table 3) show no significant¹ differences. Furthermore, total and pooled chi-square values indicate no difference between catches, leading to the conclusion that the relative efficiency of the two net strings is equal.

DIRECTION OF SET

In two pairs of sets (*Bertha Ann* 44—*George B. Kelez* 10 and *Bertha Ann* 45—*George B. Kelez* 11), the net strings of the two vessels were set at a 90 degree angle to each other to test whether direction of set (direction of net lay) has any influence on the catch of a gillnet string. One vessel set downwind and moored to the downwind end of its string; the other set crosswind and moored to the end of its string. Because of the wind effects on the vessels during the night, the vessel which set crosswind fell off with the wind, bowing the string. In the morning, the string was "U" shaped, the distal end still in the same direction with the vessel end downwind and parallel to the string of the other vessel (Fig. 3). Therefore

¹ Throughout this paper, probabilities of 5 percent or less are considered to be significant.

TABLE 4. Comparison of salmon catches of gillnets set in different directions¹.

Species and age	Set number		Catch		Total	Average	Chi-square	d.f.	Probability
	Bertha Ann	George B. Kelez	Bertha Ann	George B. Kelez					level
									Percent
<i>Sockeye</i>									
1-winter-at-sea	44	10	15	73	88	44.0	38.23	1	<0.1
	45	11	12	9	21	10.5	0.43	1	50-60
2-winters-at-sea	44	10	47	73	120	60.0	5.63	1	1-2.5
	45	11	22	30	52	26.0	1.23	1	20-30
<i>Chum</i>									
2-year-old	44	10	19	28	47	23.5	1.72	1	10-20
	45	11	12	18	30	15.0	1.20	1	20-30
3-year-old and older	44	10	21	23	44	22.0	0.09	1	70-80
	45	11	4	15	19	9.5	6.37	1	1-2.5
Total			152	269	421	210.5	16.26	1	<0.1
Pooled							54.90	8	<0.1

¹ Excluding *Bertha Ann* monofilament nets and four 4½-inch nets of *George B. Kelez*.

ifferences in catch of the two strings are not necessarily due only to direction of set, but may be due to factors as leading in the curved string, having one of the bowed string in the shadow of the other end, to

chi-square tests between the catches of the two vessels by species and age group show significant differences in three of eight comparisons as do total and pooled tests (Table 4), leading to the conclusion that either the shape of the net string (straight, curved) or the direction of net lay can influence the salmon catch of a gillnet.

DISTANCE BETWEEN SETS

Three pairs of sets (*Bertha Ann* 46—*George B. Kelez*

12, *Bertha Ann* 47—*George B. Kelez* 13, *Bertha Ann* 48—*George B. Kelez* 14), the net strings of the two vessels were set in the same direction with distances of two, four and eight miles between them (Fig. 3). The catches of each of these pairs of sets (Table 5) were also analyzed with chi-square tests by species and age group. In these tests, there was a significant difference in only one of twelve comparisons and no difference in total or pooled tests. This indicates that there is no measureable change in sockeye and chum salmon abundance over distances of up to eight miles at the observed abundance levels. However, the combined catches of the two vessels did change significantly over the 90 miles between these stations in two of four cases (2-winter-at-sea sockeye and 2-year-old chum) (Table 6).

TABLE 5. Comparison of salmon catches of gillnets set at two, four and eight miles apart¹.

Species and age	Set number		Catch		Total	Average	Chi-square	d. f.	Probability level	Distance apart
	Bertha Ann	George B. Kelez	Bertha Ann	George B. Kelez						
Sockeye										
1-winter-at-sea	46	12	14	12	26	13.0	0.15	1	60-70	2 miles
	47	13	14	8	22	11.0	1.64	1	20	4 miles
	48	14	4	9	13	6.5	1.92	1	10-20	8 miles
2-winters-at-sea	46	12	13	25	38	19.0	3.79	1	5-10	2 miles
	47	13	3	10	13	6.5	3.77	1	5-10	4 miles
	48	14	3	3	6	3.0	0	1	—	8 miles
Chum										
2-year-old	46	12	9	5	14	7.0	1.14	1	20-30	2 miles
	47	13	13	15	28	14.0	0.14	1	70-80	4 miles
	48	14	24	12	36	18.0	4.00	1	2.5-5	8 miles
3-year-old and older	46	12	6	13	19	9.5	2.58	1	10-20	2 miles
	47	13	11	7	18	9.0	0.89	1	30-40	4 miles
	48	14	7	3	10	5.0	1.60	1	20-30	8 miles
Total			124	122	246	123.0	0.02	1	80-90	
Pooled							21.64	13	5-10	

¹ Excluding *Bertha Ann* monofilament nets and four $4\frac{1}{2}$ -inch nets of *George B. Kelez*.

TABLE 6. Determination of change in salmon abundance over 90 miles¹.

Species and age	Combined catches in set nos :			Total	Average	Chi-square	d.f.	Probability level
	<i>Bertha Ann</i> 46 and <i>George B.</i> <i>Kelez</i> 12	<i>Bertha Ann</i> 47 and <i>George B.</i> <i>Kelez</i> 13	<i>Bertha Ann</i> 48 and <i>George B.</i> <i>Kelez</i> 14					
<i>Sockeye</i>								
1-winter-at-sea	26	22	13	61	20.3	4.37	2	<i>Percent</i> 10-20
2-winters-at-sea	38	13	6	57	19.0	29.79	2	<0.1
<i>Chum</i>								
2-year-old	14	28	36	78	26.0	9.54	2	<0.1
3-year-old and older	19	18	10	47	15.7	3.10	2	20-30
Total	97	81	65	243	81.0	6.32	2	2.5-5

¹ Excluding *Bertha Ann* monofilament nets and four $4\frac{1}{2}$ -inch nets of *George B. Kelez*.

TABLE 7. Catches of pink, coho and chinook salmon and steelhead trout in paired gillnet sets¹.

Vessel	Set no.	Pink	Coho	Chinook	Steelhead
<i>Bertha Ann</i>	44	0	0	0	2
<i>George B. Kelez</i>	10	0	1	0	0
<i>Bertha Ann</i>	45	0	1	0	3
<i>George B. Kelez</i>	11	1	0	0	9
<i>Bertha Ann</i>	46	0	0	0	4
<i>George B. Kelez</i>	12	0	0	0	7
<i>Bertha Ann</i>	47	0	0	0	4
<i>George B. Kelez</i>	13	1	0	0	2
<i>Bertha Ann</i>	48	0	2	0	11
<i>George B. Kelez</i>	14	0	2	0	7
Totals <i>Bertha Ann</i>		0	3	0	24
<i>George B. Kelez</i>		2	3	0	25

¹ Includes all nets of both vessels.

OTHER SALMONIDS

Pink (*O. gorbuscha*), coho (*O. kisutch*) and chinook (*O. tshawytscha*) salmon and steelhead trout (*Salmo gairdneri*) are also of primary interest in the high seas sampling program. However, the catches of these species (Table 7) were so low that statistical comparisons within pairs of sets were not feasible. There was no apparent difference in the distribution of these fish between catches of the vessels in any of the pairs of sets.

INCIDENTAL CATCH

The only other species encountered during this study were the Pacific mackerel (*Pneumatophorus*

japonicus)¹ and pomfret (*Brama raii*). The catches of these two species, corrected to eliminate the monofilament catch of the *Bertha Ann* and to equate the effort of the two vessels, are shown in Table 8. The results of chi-square tests indicate significant differences in the catches of pomfret in each pair of sets. For this species, it would appear that direction of set or net shape does affect the catch. Also, the distribution of both the pomfret and Pacific mackerel is probably much less even than that of salmon as shown by the differences of catch between net strings set two, four and eight miles apart.

DISCUSSION AND CONCLUSIONS

The direction of lay or shape of the gillnet string can, apparently, affect the catch of sockeye and chinook salmon and pomfret. This can be interpreted to mean that the majority of fish of these three species did not move randomly but, instead, over the period of one night, moved primarily in one direction. Therefore, measures of relative abundance obtained through gillnet samples should be used with this variable in mind.

In the station pattern followed during the series of paired sets, the decrease in total salmon catch indicated a decrease in salmon abundance from south to north. However, the paired sets with two, four and eight miles between net strings failed to show any significant difference in catches of sockeye and chinook.

¹ *Scomber japonicus*.

TABLE 8. Catches of Pacific mackerel and pomfret in paired gillnet sets¹.

Species	Set		Catch		Total	Average	Chi-square	d. f.	Probability level ²
	<i>Bertha Ann</i>	<i>George B. Kelez</i>	<i>Bertha Ann</i>	<i>George B. Kelez</i>					
Pomfret	44	10	43	111	154	77.0	30.03	1	<0.1
	45	11	62	19	81	40.5	22.83	1	<0.1
	46	12	203	129	332	166.0	16.49	1	<0.1
	47 ²	13	60	19	79	39.5	21.28	1	<0.1
	48 ²	14	47	27	74	37.0	5.41	1	1-2.5
Pacific mackerel	44	10	7	15	22	11.0	2.91	1	5-10
	45	11	2	0	2	1.0	—	—	—
	46	12	0	0	0	—	—	—	—
	47 ³	13	8	1	9	4.5	5.44	1	1-2.5
	48 ³	14	6	41	47	23.5	26.06	1	<0.1

¹ Excluding *Bertha Ann* monofilament nets and four 4½-inch nets of *George B. Kelez*.

² *Bertha Ann* multifilament catches computed using 84 percent of total pomfret catch to allow for catch of monofilament net. Individual net catches not available.

³ *Bertha Ann* multifilament catches computed using 69 percent of total mackerel catch to allow for catch of monofilament net. Individual net catches not available.

mon, implying that the populations of these species in the study area are well dispersed and that the abundance gradients are gradual. This is contrasted with the apparently uneven and perhaps clustered distributions of pomfret and Pacific mackerel.

Because of the limited scope of this study and the lack of replicates at the various stations, the above conclusions should be extended to other areas, times, and abundance levels only with caution.

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An Experimental Study of the Effect of Temperature on the Incubation Time, Development, and Growth of Pacific Sardine Embryos and Larvae

REUBEN LASKER

Incubation time, development, and growth of individual Pacific sardine eggs and larvae were studied in relation to environmental temperatures between 11 and 21 C. Time from spawning to hatching decreased with increasing temperature from approximately 140 hr at 11 C to 34 hr at 21 C. Maximum growth occurred in yolk sac larvae between 16 and 17 C before shrinking due to starvation. A functional jaw and pigmented eyes failed to develop in sardine larvae at temperatures below 13 C. In contrast, the northern anchovy, a clupeoid inhabiting much of the same ecological range as the sardine, hatches sooner and develops normally at these low temperatures. A comparison of incubation times deduced from field studies with these experimental results showed a close correspondence at all but extreme temperatures.

INTRODUCTION

THE Pacific sardine, *Sardinops caerulea* (Girard), spawns planktonic eggs at temperatures ranging from 13 to 24 C (Ahlgren 1954). The importance of the effect of temperature on "brood strength" and larval survival has been emphasized (Hela and Laevastu 1961) but the incubation time, growth, and development of the sardine in relation to environmental temperatures have not been observed for this species under controlled conditions.

The purpose of this investigation was to determine temperature and time relationships with respect to the physiological parameters of incubation time (time from spawning to hatching), development (eye pigmentation and jaw formation), and growth (as measured by increase in length of the larva). Single larvae were studied in all instances to assess their individual variability of development and growth. For comparison, data were collected on a limited number of eggs and larvae of the northern anchovy (*Engraulis mordax* Girard) which may be a competitor of the sardine.

METHODS AND MATERIALS

Sardine eggs were obtained from April to September 1962 with a 1-m plankton net towed at the surface off the coast of San Diego, California. All collections were made between 9 AM and noon. Most eggs caught in a single haul were in the same stage of development and usually had been spawned during the night prior to collection. Temperature changes were avoided by

putting the jars containing eggs into a styrofoam-insulated box for transportation to the laboratory. Surface water temperatures ranged from 12.8 to 22.2 C.

A recent advance in the study of the effect of temperature on biological processes has been made by the construction of an aluminum temperature-gradient block in which as many as 18 different temperatures (± 0.1 C) can be maintained simultaneously (Thomas, Scotten, and Bradshaw 1963). Essentially, the apparatus is an aluminum block drilled with holes to accommodate 30-ml screw-capped test tubes. Refrigerated water is circulated at one end of the block while hot water is circulated at the other. Because of the even conduction of heat by the aluminum, a uniform gradient of temperature is established. The whole apparatus is insulated with 2-inch-thick styrofoam encased in plywood.

A single sardine egg at a known stage of development was put into each test tube containing 25-ml seawater previously equilibrated to the temperature of the block position.

Because sardine larvae become more active as they develop, it was necessary to immobilize them for daily measurement; therefore, 0.02% MS-222 (Tricaine methanesulfonate) was used to anesthetize the larvae. Each larva was removed from the seawater with a large-bore pipette and put into a Syracuse dish containing seawater with MS-222 at the same temperature. After the larva was measured with an ocular micrometer, it was rinsed once in seawater and returned to its test tube.

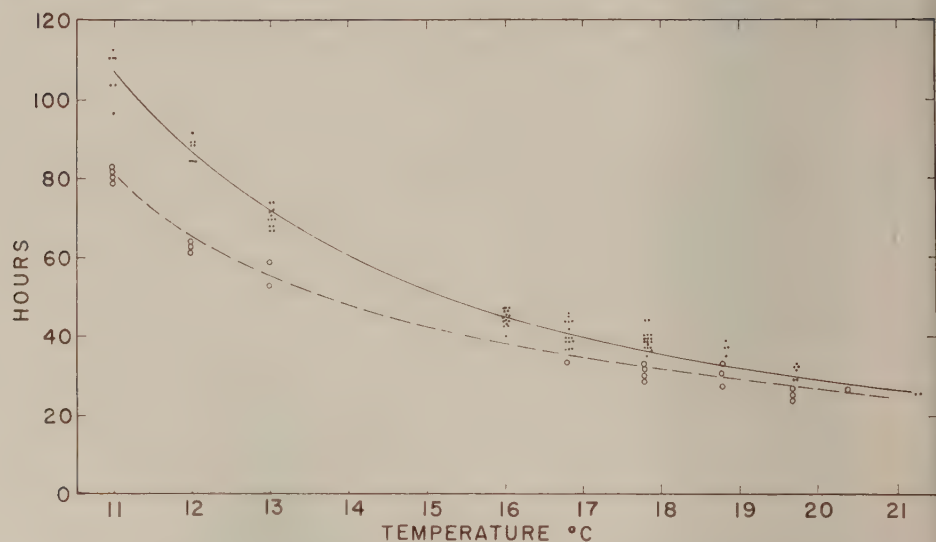


Fig. 1. Observed times from developmental stage IV to hatching at different temperatures. Pacific sardine eggs (solid line); northern anchovy eggs (broken line). Each dot represents a single animal.

Mortality of the larvae was very high at temperatures below 14 C. At the lower temperatures, larvae in the laboratory seem susceptible to damage from handling and death from bacterial infection. Electron micrographs reveal that the larval integument is a two-cell layer, 5 μ thick. Damage to this fragile skin is difficult to avoid. Significant reductions in mortality (up to 80%) can be achieved by immersing the eggs in 50 ppm each of penicillin-G and streptomycin sulfate. However, under these experimental conditions there was evidence that the use of antibiotics accelerated development in some instances and possibly delayed it in others. Therefore, only those animals developing normally at low temperatures without antibiotics were used in our analyses.

Developmental stages of sardine and anchovy embryos are described following the nomenclature of Ahlstrom (1943).

DEVELOPMENT AND GROWTH OF LARVAE

Incubation time.—Ahlstrom (1954) published a regression line for the incubation time of Pacific sardine eggs with temperature as deduced from stage of development of eggs taken by plankton nets at different temperatures in the sea. This is possible because sardine spawning is restricted to

the period between sunset and midnight. Ahlstrom's data encompass the time from spawning to the stage (XI) just immediately before hatching. My experimental data cover the time from stage IV (blastodisc stage, germinal ring at the equator) to hatching because I was unable to obtain newly spawned eggs. Miller (1952) observed that the time of development of sardine eggs from fertilization to stage IV was 13 hr at the average temperature of 16.8 C. Assuming that my experimentally determined curve for the period from stage IV to hatching applies also to time for development from spawning to stage IV, I adjusted my data to include the earliest stages by increasing the time proportionately to that for 16.8 C. Incubation time decreases with increasing temperature from approximately 140 hr at 11 C to 34 hr at 21 C (Fig. 1).

The experimental results for incubation time related to temperature are compared in Table 1 with those deduced statistically by Ahlstrom (1954) from field collections of the same species. The two sets of data correspond within 5% of each other between 13 and 19 C. At higher and lower temperatures there is a wider divergence, 13–18% between 11 and 12 C and over 8% at 20 and 21 C. The larger differences may be

TABLE 1. INCUBATION TIMES OF PACIFIC SARDINE EGGS AT DIFFERENT TEMPERATURES.

Temperature C	Incubation Time in Hours ¹ (this study)	Incubation Time in Hours (Ahl- strom 1954)	Percentage Difference ²
11	140	114	18.5
12	115	100	13.0
13	93.0	88	5.3
14	78.5	77	1.9
15	68.1	68	0.1
16	60.2	60	0.3
17	53.7	53	1.3
18	48.4	46	5.0
19	43.2	41	5.1
20	39.3	36	8.4
21	34.0	31	8.8

¹ Corrected for time from spawning to stage IV based on field observations by Miller (1952).

² Percentage difference is calculated by dividing the difference in hours at a temperature with the time found experimentally ($\times 100$).

due to the limited field data usually available for the extremes of the environmental temperature range of the sardine and to the fact that Ahlstrom (1954) calculated incu-

bation time only to stage XI of egg development and not to hatching itself.

The formula $T = at^b$, where T = incubation time, a = constant, and t = temperature in degrees C, can be used to describe the experimentally determined curve and is shown in Fig. 2. The log-log transformation of this formula adequately describes the data and yields the formula $\log T = \log a + b \log t$, or in the case of this study,

$$T = 21759 t^{-2.11865} \quad (1)$$

and by comparison, Ahlstrom's (1954) data calculated from field collections yield the formula

$$T = 17319 t^{-2.0479985} \quad (2)$$

and Ito's (1958) data for the incubation time of a related species, *S. melanosticta*, are described by the formula

$$T = 19649 t^{-2.06009} \quad (3)$$

Development of the jaw and pigmented eyes.—Because ultimate survival of the sardine larva may depend on when feeding begins (Lasker 1962) and/or the length of time the sardine larva is an easy prey to its

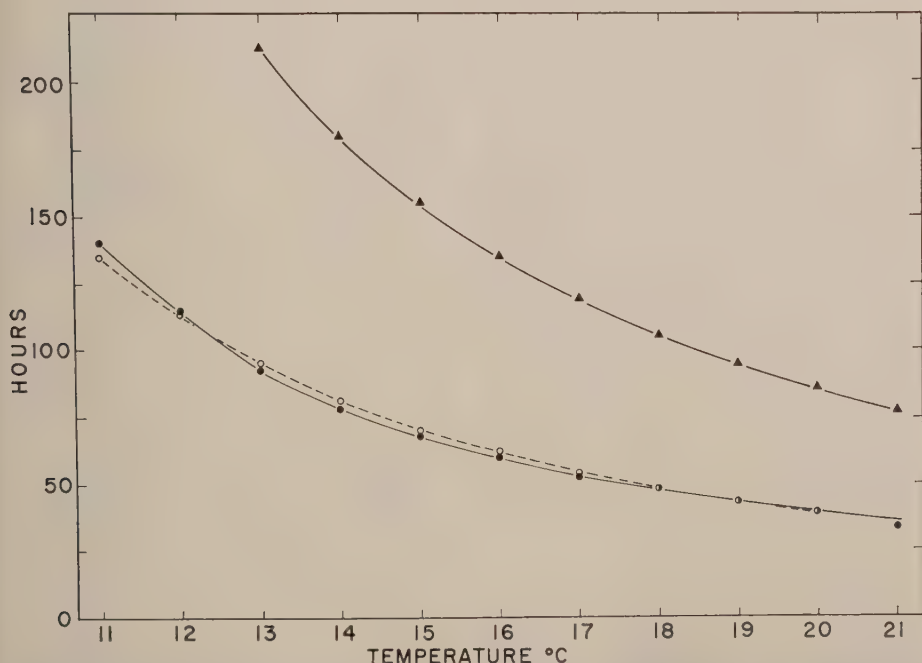


Fig. 2. Incubation times (●-●) and times to develop a movable jaw and fully pigmented eyes (▲-▲) in the Pacific sardine in relation to temperature. The dotted line was calculated from $T = 21759 t^{-2.11865}$.

TABLE 2. COMPARATIVE RATE OF SARDINE EGG INCUBATION AND LARVAL JAW DEVELOPMENT AND EYE PIGMENTATION AT DIFFERENT TEMPERATURES. Rate at 21 C = 1.00 (incubation time, 34 hr; eye pigmentation and jaw development, 67 hr).

Temperature C	Incubation Time	Eye Pigmentation and Jaw Development
11	4.12	Did not develop
12	3.38	Did not develop
13	2.74	2.77
14	2.31	2.33
15	2.00	2.02
16	1.77	1.76
17	1.58	1.54
18	1.42	1.37
19	1.27	1.22
20	1.16	1.11
21	1.00	1.00

predators (Murphy 1961), specific information was sought on the time required for the sardine larva to develop a functional jaw and fully pigmented eyes. The jaw as shown in Fig. 3C, which forms simultaneously with complete eye pigmentation, is referred to as a functional jaw. At this stage of development the lower jaw can be moved freely by the animal. In Fig. 3 (A and B) are pictured the anatomical changes occurring during development of the eye and jaw. Table 2 shows the comparative rates at each temperature to attain complete eye and jaw development (rate at 21 C = 1.00) and may be compared with the rates for incubation time. The comparative rates of development as measured by incubation time and time for jaw development are the same throughout the embryonic and larval life of the sardine. In Fig. 2 a plot of time from spawning to formation of a functional jaw and uniform eye pigmentation is included for comparison. Complete eye pigmentation and a functional jaw develop in 213 hr at 13 C and 67 hr at 21 C. At temperatures lower than 13 C all sardine larvae in the laboratory failed to develop pigmented eyes and functional jaws.

An experiment was performed to ascertain if the appearance of a functional jaw is coincident with the complete opening of the digestive tract. Developing sardine larvae were put into a dense suspension of the unicellular alga, *Platymonas subcordiformis*, which is 17 μ in diameter. Larvae at dif-

ferent stages of development were examined microscopically for algal cells throughout the digestive tract. The appearance of algal cells in the intestine showed that in all cases the lumen of the tract is completely open from mouth to anus at the same time or a few hours prior to the formation of a functional jaw as shown in Fig. 3C.

Since the rate of incubation is more easily determined than other aspects of larval fish development, the former may be used as an index of jaw development rate because of

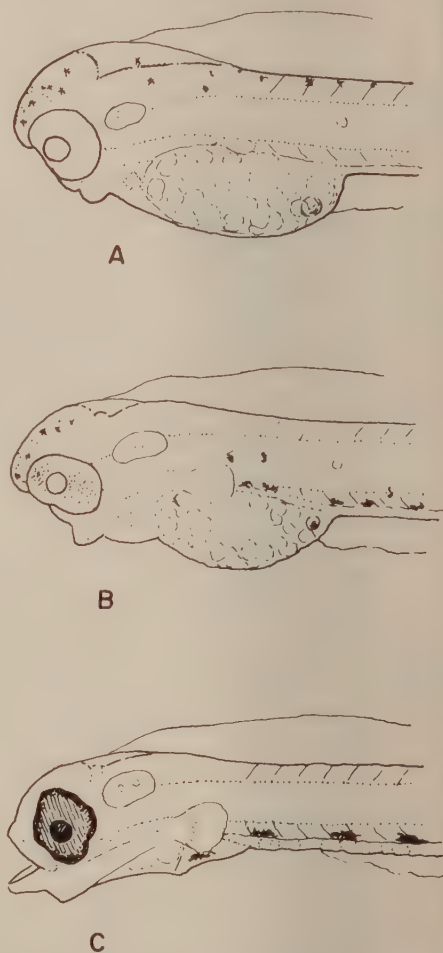


Fig. 3. Larval sardine anatomical changes during development of eyes and jaw. At 17 C stage A is attained at approximately 95 hr after spawning, stage B at 105 hr, and stage C at 120 hr.

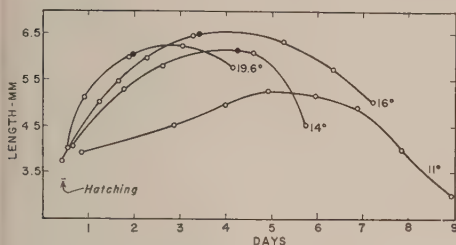


Fig. 4. Typical growth curves (increase in length) of individual sardine larvae at four different temperatures. (●) indicates when a movable jaw and fully pigmented eyes are developed.

the similarities in rates of the two processes when compared to their respective rates at 21 C as shown in Table 2.

Growth of the pelagic larva.—Larvae incubated at 11 to 13 C rarely achieve the maximum lengths attained at higher temperatures before shrinking. This may be due to a differential effect of temperature on metabolism and a possible reduction of the high incorporation efficiency of yolk proteins (Lasker 1962) at these low temperatures. In all instances (except for temperatures below 13 C) the eyes pigment and the jaw develops prior to shrinking due to tissue resorption (Fig. 4).

In Table 3 the means, standard deviations, and ranges of sardine larval lengths are given for temperatures ranging from 11 to 21 C. At all temperatures the sardine larva averages 3.75 mm in length when it emerges from the egg. Growth curves of selected typical individual larvae at 4 different temperatures are shown in Fig. 4. At 16–17 C, individual larvae reach their maximum lengths before shrinking.

Larval developmental processes proceed at much the same relative rates as incubation times with increasing temperature. These data show that the larvae cannot see or feed at least until approximately 65–75 hr after hatching at optimal growth temperatures (16–17 C). This interval is 43–46 hr after hatching in warmer waters, such as those found in the sardine spawning grounds off Baja California, where spawning temperatures may be as high as 20–21 C. Although the larvae are expending more energy for metabolism at the expense of growth at higher temperatures, this may be offset by the significantly earlier development of anatomical features necessary for survival.

Northern anchovy egg and larval development.—Eggs of the northern anchovy obtained in December 1962 and January 1963 in plankton hauls were observed at the same experimental temperature range as the sardine. The incubation times of the anchovy eggs are less than those of the sardines at all temperatures. A comparison of times from stage IV to hatching in relation to temperature is compared with the similar curve obtained for the sardine (Fig. 1).

Three notable differences between the 2 species were observed: (1) anchovy eggs hatch as much as a day earlier at 11 and 12 C with the difference decreasing with increasing temperature, (2) anchovy larvae develop a functional jaw at 11 and 12 C while sardine larvae do not, and (3) the hatching length of anchovy larvae averages 2.7 mm and the maximum length attained at any temperature during yolk sac development is approximately 4.8 mm.

The northern anchovy has increased in abundance off the coast of California while the Pacific sardine has remained at a relatively low level after the large year classes of 1947 and 1948. Ahlstrom (1961) pointed out that the threshold temperature for sardine spawning is about 13 C with peak spawning at 16 C and that for the anchovy is 11 C with peak spawning at 14 C. From the experimental results presented here it would appear that the anchovy is at a competitive advantage at low temperatures (11 and 12 C) because it completes jaw development and is able to feed whereas the sardine does not. At higher temperatures, the rates of development for the anatomical features necessary to survival (jaw development, eye pigmentation, etc.) are slightly earlier in the anchovy than in the sardine. The difference between rates of development of these two clupeoid fishes are slight at higher temperatures in the environmental range, but the anchovy appears to be at a marked advantage at low temperatures as far as the time to commence feeding is concerned.

DISCUSSION

Incubation times have been deduced from field collections for several sardine species: *Sardinops caerulea* (Ahlstrom 1943, 1954), *Sardinops melanosticta* (Ito 1958), *Sardina pilchardus* (Gamulin and Huré 1955). The present study permits comparison in detail

TABLE 3. LARVAL SARDINE LENGTHS IN MILLIMETERS WITH STANDARD DEVIATIONS AT DIFFERENT TEMPERATURES (C).

Time (Days)	11°				12°				13°			
	N	$\bar{X}$	sd	Range	N	$\bar{X}$	sd	Range	N	$\bar{X}$	sd	Range
Hatching	7	3.76 ± 0.15		3.60-4.00	9	3.77 ± 0.20		3.40-4.10	8	3.73 ± 0.16		3.50-4.00
1	4	4.30		4.00-4.55	11	4.50 ± 0.23		4.00-4.90	17	4.50 ± 0.24		4.20-4.90
2	4	4.78		4.30-5.40	8	4.71 ± 0.29		4.35-5.20	11	4.97 ± 0.41		4.50-5.70
3	2	4.98		4.80-5.15	6	5.04 ± 0.45		4.40-5.70	9	5.46 ± 0.45		4.70-6.20
4	2	5.15		5.10-5.20	3	5.50		5.20-5.90	7	5.74 ± 0.42		5.40-6.45
5	2	5.15		5.10-5.20	1	5.60			5	5.69		5.00-6.30
6	1	4.95			1	5.15			4	4.98		3.75-6.30
7	1	4.20										
8	1	3.30							1	6.50		
9									1	5.45		
Time (Days)	14°				15°				16°			
	N	$\bar{X}$	sd	Range	N	$\bar{X}$	sd	Range	N	$\bar{X}$	sd	Range
Hatching	16	3.98 ± 0.14		3.75-4.20					21	3.75 ± 0.25		3.10-4.05
1	22	4.80 ± 0.20		4.40-5.05	17	5.14 ± 0.44		4.50-5.70	19	5.01 ± 0.25		4.50-5.40
2	19	5.39 ± 0.27		4.80-5.75	20	5.59 ± 0.35		5.10-6.50	23	5.68 ± 0.28		5.15-6.15
3	9	5.65 ± 0.36		5.15-6.10	10	5.96 ± 0.32		5.55-6.40	11	5.99 ± 0.15		5.65-6.20
4	8	5.91 ± 0.33		5.45-6.35	5	6.11		5.80-6.60	9	6.23 ± 0.11		6.00-6.35
5	7	5.42 ± 0.71		4.30-6.30	5	6.20		6.00-6.65	8	6.29 ± 0.18		6.00-6.50
6					4	6.03		5.90-6.15	8	6.23 ± 0.29		5.80-6.50
7					1	5.85			1	5.50		
8	1	6.50										
9	1	6.15			2	5.80 ¹		5.65-5.95	4	5.79 ¹		5.25-6.15
10									1	5.10 ²		
Time (Days)	16.8°				17.8°				18.8°			
	N	$\bar{X}$	sd	Range	N	$\bar{X}$	sd	Range	N	$\bar{X}$	sd	Range
Hatching	14	3.74 ± 0.22		3.15-3.95	5	3.69		3.60-3.85	4	3.86 ³		3.75-4.00
1	16	5.20 ± 0.16		4.95-5.50	16	5.27 ± 0.19		4.90-5.60	18	5.46 ± 0.18		5.10-5.70
2	22	5.78 ± 0.20		5.20-6.10	22	5.86 ± 0.23		5.40-6.40	25	5.98 ± 0.20		5.60-6.45
3	13	6.14 ± 0.21		5.80-6.50	19	6.06 ± 0.22		5.60-6.50	18	6.09 ± 0.15		5.80-6.40
4	10	6.25 ± 0.24		6.00-6.75	10	6.18 ± 0.28		5.85-6.65	8	6.06 ± 0.15		5.85-6.35
5	10	6.26 ± 0.31		5.80-7.00	6	6.03 ± 0.45		5.60-6.70	8	5.87 ± 0.26		5.40-6.15
6	5	5.86		5.60-6.10	6	5.73 ± 0.53		5.15-6.45	7	5.66 ± 0.29		5.25-6.05
7	1	5.45							1	5.25		
8												
9	1	5.60										
Time (Days)	19.6°				20.5°				21.3°			
	N	$\bar{X}$	sd	Range	N	$\bar{X}$	sd	Range	N	$\bar{X}$	sd	Range
Hatching	4	3.73		3.60-3.80	12	5.10 ⁴ ± 0.12		4.95-5.35				
1	18	5.36 ± 0.19		5.05-5.70	12	5.46 ± 0.16		5.30-5.75	3	5.43		5.40-5.45
2	24	5.75 ± 0.20		5.45-6.25	7	5.93 ± 0.13		5.80-6.10	3	5.87 ⁵		5.70-6.00
3	16	5.93 ± 0.25		5.65-6.50	11	5.88 ± 0.19		5.50-6.15	5	5.90		5.70-6.00
4	5	5.84		5.70-6.10	3	5.77		5.70-5.85	6	5.68 ± 0.22		5.30-5.95
5	5	5.77		5.50-6.00	1	5.75			1	5.30		
6	1	5.55			1	4.40			1	4.10		

¹ 8.6 days.² 9.7 days.³ 0.1 day.⁴ 0.5 day.⁵ 1.8 days.

of one of these (Ahlstrom 1954) with data obtained by laboratory observation. The accuracy of the field data and its analysis have been verified for the major portion of the experimental range, although where field data are lacking (at the extremes of the environmental range) greater variations are found.

Analysis of the data shows that incubation time does not decrease by a fixed percentage with each degree increase in temperature. A log-log transformation of the formula $T = at^b$ fits both the experimental and the field data. This may be a general relationship, but requires experimental data on other fish species to test its applicability.

If predation is a major factor in larval sardine mortality, time elapsed before development of a uniformly pigmented eye may be a relative index of survival at different temperatures. Murphy (1961) used incubation time as an index of sardine survival. The data published here show that both rates are temperature dependent and therefore closely related. Ahlstrom (1954) has shown that there is a marked under-sampling of sardine larvae in daytime as indicated by comparison of night and day plankton tow catches of sardine larvae. His data show that small larvae in the size range where a pigmented eye is not developed are caught about as often at night as in the daytime. This implies that vision and active dodging are the main factors involved.

A comparison of the relative rates of jaw development and uniform eye pigmentation at different temperatures shows that sardine larvae at 13 and 15 C spend, respectively, 3 and 2 times as long in comparatively vulnerable stages of development as they do at 21 C. Thus a 2-degree decrease in temperature can prolong the rate of development about one-third and larval survival may decrease concomitantly.

ACKNOWLEDGMENTS

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Moulting Frequency of a Deep-sea Crustacean, *Euphausia pacifica*

Most of the observations on moulting in crustaceans have been confined to littoral animals kept in aquaria¹. Because planktonic, deep-sea crustaceans are difficult to maintain in the laboratory there has been virtually no information available on moulting frequency in these forms. In connexion with experiments designed to determine filtering rates and the quantitative aspects of carbon metabolism in the deep-sea planktonic euphausiid shrimp, *Euphausia pacifica*², observations were made on the moults and moulting frequency of this animal.

E. pacifica is an important and ubiquitous component of the deep-sea plankton in a broad oceanic region ranging from the north of Japan across the Bering Sea to Baja, California, Mexico³. In the laboratory *E. pacifica* has been kept alive for more than 7 weeks on a diet of the green flagellate *Dunaliella primolecta* and/or *Platymonas subcordiformis*.

Each animal, ranging in dry weight from 1.2 to 4.8 mg, was kept in 1 l. of sea water and the water changed every three days. One drop of algal suspension was added daily, but no attempt was made to determine how much food was actually ingested by the euphausiids. All containers were examined daily for cast moults. Recovered moults were rinsed in distilled water, dried at 80° C on a microscope slide and weighed with a Cahn electrobalance to ± 0.002 mg. Temperature was not rigidly regulated but normally held within narrow limits. Only those animals which had moulted more than once are included in this work.

The results summarized in Table 1 show that within the range of experimental temperatures (9°–14° C) the moulting frequency was 5 days with a standard deviation of one day (range 4–7 days). Each cast moult averaged 10 per cent of the animal's dry weight. There is no apparent correlation of moulting frequency with temperature or age of the animal, although it is quite likely that furcilia and calyptosis stages have more frequent moults as do most developing crustaceans¹. Temperature may have had a small effect, but because observations were made daily and not hourly these may have been masked.

One animal lived 50 days in the laboratory and had passed through 11 moults, while another of similar size (1.3 mg) went through 10 moults in 36 days. Ash weights averaged 54.4 per cent of the moult dry weight (range for four determinations 52.9–56.9 per cent) and the organic components 45.6 per cent by difference. Nitrogen was

Table 1. MOULTING FREQUENCY OF *Euphausia pacifica*
(S.D., standard deviation)

Euphausiid	Temperature range	Final animal dry weight (mg)	No. of moults produced	Average weight moult	Time (days) alive in laboratory	Average moulting frequency (days)	Moult = percentage of animal dry weight
1	9.5-12.5	2.833	2	0.247	10	5	10.6
2	9.8-11.2	2.143	2	0.182	14	7	8.5
3	9.8-11.2	4.810	2	0.479	8	4	10.0
4	9.8-13.7	4.800	3	0.416	18	6	8.7
5	9.8-13.7	—	3	—	15	5	—
6	10.8-14.5	1.541	2	0.198	10	5	12.9
7	10.8-14.5	1.975	3	0.167	12	5	8.4
8	10.8-14.5	—	2	0.187	14	7	—
9	10.8-14.5	—	2	0.157	12	6	—
10	10.8-14.5	1.244	2	0.109	12	4	12.7
11	12.3-13.2	—	3	0.249	9	4	—
12	12.3-13.2	—	2	0.263	13	4	—
13	12.5-13.2	4.798	3	0.327	12	6	6.8
14	12.5-13.2	—	2	0.161	9	5	—
15	12.8-14.3	1.300	11	0.128	7	4	9.8
16	12.8-14.2	3.476	3	0.380	50	5	10.9
17	15.4-17.5	—	2	0.146	12	4	—
18	15.4-18.9	1.305	10	0.211	8	4	16.1
19	15.4-18.9	1.326	8	0.121	36	5	9.1
Av. 5 ± 1 (S.D.)						Av. 10.4 ± 2.4 (S.D.)	

1.5-2.5 per cent of the moult dry weight or between 3 and 5 per cent of the ash-free moult dry weight.

There are large populations of euphausiid shrimps throughout the deep oceans. If moulting occurs in the sea as frequently as it has been observed in the laboratory, the moults represent a tremendous amount of organic material added daily to the rain of materials known as detritus in the sea. For example, each euphausiid contributes its full body-weight in cast moults every 50 days. The importance of organic detritus in the sea was discussed by Parsons and Strickland⁴. The results presented here show that the moults of planktonic crustaceans could contribute a substantial portion of this material.

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VARIATIONS IN TIME AND INTENSITY OF SETTING OF THE STARFISH, *ASTERIAS FORBESI*, IN LONG ISLAND SOUND DURING A TWENTY-FIVE-YEAR PERIOD

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The common starfish, *Asterias forbesi* (Desor), is found in greatest concentrations in the waters of southern New England, principally in Long Island Sound. The latter is a semi-enclosed basin approximately 100 nautical miles long and occupying an area of about 925 square miles. The Sound's greatest width of about 17 miles is along the line drawn perpendicular to the Long Island shore from Branford, Connecticut. The width decreases gradually from this line in both directions, being confined eventually to only about one mile at its west entrance and to approximately eight miles at the eastern end.

The average depth of the Sound is approximately 60 feet, and the greatest depth of about 306 feet, recorded during our surveys, was near the Sound's extreme eastern end, a few miles southwest of Fishers Island. The eastern part, in general, is somewhat deeper than the western, while the middle and the deepest part of the Sound is relatively level and averages about 90 feet in depth (Loosanoff and Engle, 1940). Information on various aspects of oceanography of Long Island Sound is given by Riley *et al.* (1956).

Surveys of the occurrence and distribution of starfish in Long Island Sound made in different years and during different seasons have shown that these echinoderms were present in all depths from a few feet above the low water mark to 250 feet, although most of them were found near the shores in comparatively shallow water, usually less than 50 feet (Galtsoff and Loosanoff, 1939). These surveys also demonstrated that in Long Island Sound there were no seasonal migrations of starfish from shallow to deep water or *vice versa*. Their distribution was primarily influenced by the location and numbers of bottom organisms on which they feed.

Because of their common occurrence in New York and New England waters, where many centers of research in marine biology of our country originated, the starfish were subjects of studies of many biologists, including Agassiz (1877), Clark (1904), Mead (1901), and Coe (1912). However, the literature dealing with the natural history of *A. forbesi* does not offer comprehensive accounts of time and intensity of setting of this invertebrate. With the exception of a few sentences in Mead's (1901) article on starfish of Narragansett Bay, Massachusetts, and several remarks in papers of Loosanoff (1936) and Galtsoff and Loosanoff (1939) on setting of starfish in Long Island Sound, no other reports are available. Yet, considering the common occurrence of *A. forbesi* and, especially, its importance as an enemy of commercial mollusks, principally oysters, which begin to set ap-

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proximately two weeks later than the starfish (Loosanoff and Engle, 1940), such information is obviously not only of theoretical but also of practical interest and importance.

MATERIALS AND METHODS

To acquire more information on setting of starfish a study of this phase of the animal's life history was undertaken in 1937 and continued without interruption for a period of 25 years, until 1961. The observations were largely confined to the northern part of Long Island Sound, along the Connecticut shore. In some years, especially during the early part of our observations, the chain of stations established for collection of samples extended from the Thimble Islands to Westport. These stations, the number of which varied from 3 to 23 in different years, were located at depths ranging from intertidal zones to about 100 feet. Since 1944, however, with the exception of the year of 1957, observations were made at the same ten stations located at the depths of about 10, 20, and 30 feet at mean low water mark in the area extending from Bridgeport to New Haven (Fig. 1).

The results presented in this paper are based upon the data obtained from the stations located at the depths of 30 feet or less. Because of this decision, the question naturally arose whether these data would also be representative of the time and intensity of setting of starfish at greater depths of the Sound. The answer was provided by an analysis of our material collected during 1938, when a series of 10 stations was established near Stratford Point, commencing at mean

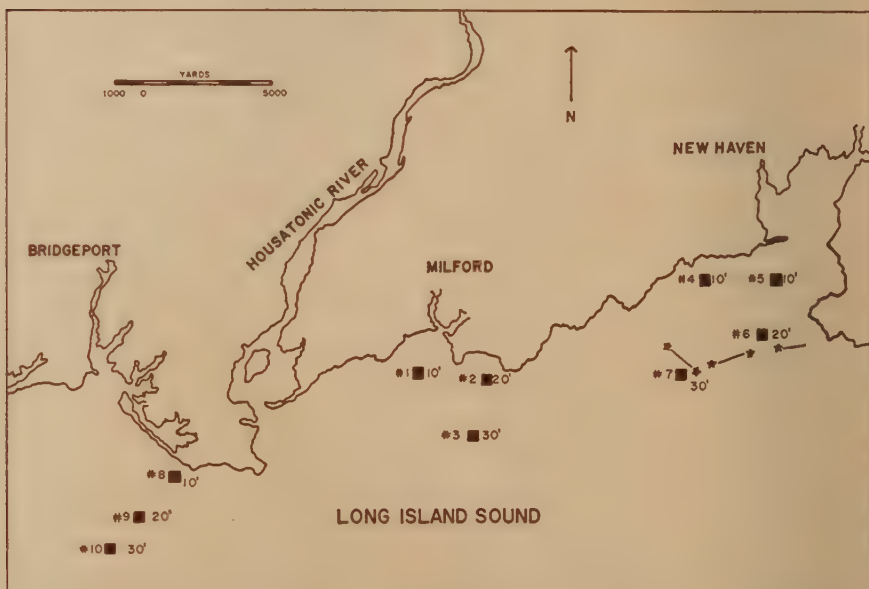


FIGURE 1. Locations and depth in feet of 10 basic stations established in Long Island Sound for observations on time and intensity of starfish setting, 1944-1961.

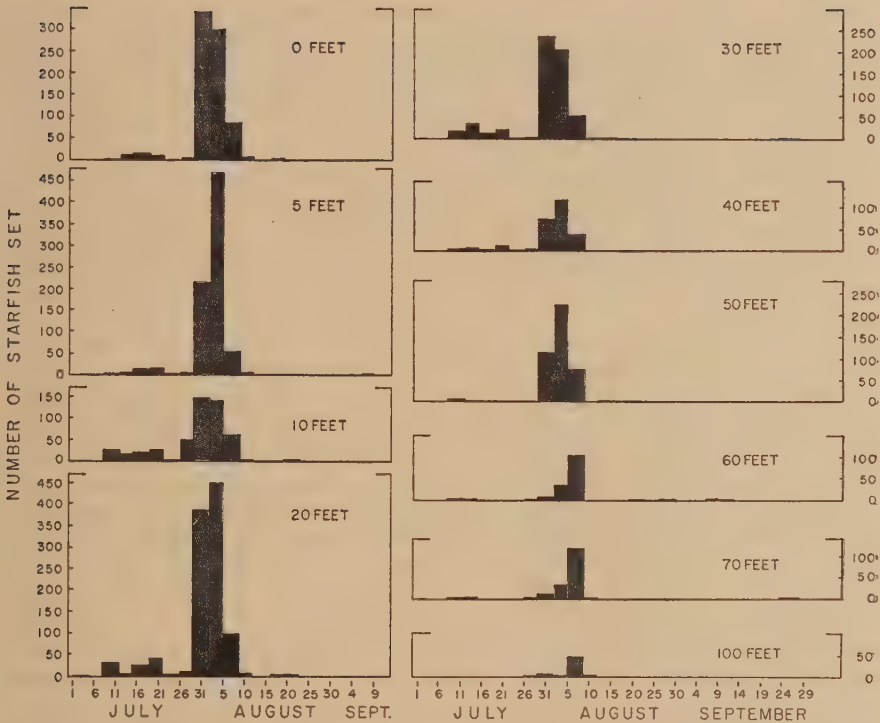


FIGURE 2. Numbers of starfish set on one hundred oyster shell-surfaces, recorded at the stations located at 10 different depths off Stratford Point. Long Island Sound, summer, 1938.

low water mark, where the Housatonic River enters the Sound, and extending almost to the middle of Long Island Sound to the depth of 100 feet. The collectors were placed at all the stations on ~~July~~^{June} 17, but no set occurred during that month (Fig. 2). The first set was found between July 1 and 5, but it was extremely light, occurring on only one collector at the 20-foot station. By July 12, however, starfish set was found at all stations except the one at 100 feet, where the first set was recorded somewhat later.

The setting at the deepest station was lighter than at any of the more shallow ones, and the duration of the setting was shorter. Nevertheless, the beginning of setting at such depths as 50, 60, and 70 feet coincided with that at the shallow stations. Furthermore, the period of heaviest setting at all stations occurred almost simultaneously (Fig. 2).

The setting ended virtually at the same time at the shallow and at the deeper stations; the last few starfish were found on September 28 at 30-foot station and at the station located at 70 feet. In 1937, nevertheless, when the series of stations in the Stratford Point area extended to a depth of only 70 feet, several single starfish were noticed on the collectors at deeper stations after the setting at more shallow stations had already ended. However, these individuals were so few that

their presence did not modify the general pattern of setting. Therefore, it may be concluded that, even though our observations on the time and intensity of setting were conducted only at stations located at depths of 30 feet or less, they were, nevertheless, quite representative for the general starfish population of Long Island Sound especially if it is remembered that most of the starfish are found near the shore in comparatively shallow water.

Our studies were designed to determine, for each year, the date of the beginning of setting, end of setting, duration of the setting period, and variations in the intensity of setting throughout the summer. Effects of several environmental factors, including temperature and salinity of the water, on the above-mentioned chronological events, and in relation to the intensity of setting within the same year and during different years, were also evaluated to provide, if possible, a reliable basis for predicting the time and intensity of setting. However, this part of our studies, representing extensive statistical analyses of the numerous variables and factors involved in propagation of starfish, will be described in another article.

The time and intensity of setting in different areas of Long Island Sound were ascertained by examining and counting starfish set on the collectors placed on the bottom. These collectors were the same type as those used for observations on setting of oysters. Since they have already been described in detail (Loosanoff and Engle, 1940), no extensive description is offered here. It is sufficient to mention that they were wire-mesh bags filled with clean oyster shells. The bags were of the same dimensions and contained approximately the same number of shells selected for their uniformity.

Twice a week, collectors at all stations were changed and brought to the laboratory to be examined. Biologists counting the recently set starfish were trained to distinguish the individuals of different ages from the time they metamorphosed to the time they were 4 or 5 days old. The counts were made on the inside surfaces of 20 shells taken from each collector, and the results were later averaged and daily intensity of setting estimated per 100 shell-surfaces. This is the criterion on which all the data offered in this article are based.

When it was decided to try this method, we suspected that a significant error might be introduced in obtaining true figures because many recently attached starfish would be washed off the shells as the collectors were brought up through many feet of water. Fortunately, the following test showed that young starfish attach themselves very securely to the shells and, therefore, are not easily washed off the collectors. A number of shells with starfish set attached were taken from collecting bags and circles were drawn in pencil around each starfish. Immediately afterward, the shells were returned to the bags and the latter were lowered to the bottom. The bags were then raised, after which the shells were re-examined and the number of empty circles, indicating washed-off starfish, counted. This test demonstrated that only a few starfish were lost.

To secure more reliable data for our general studies, two bag-collectors were used at each station. Later on, when extensive material was already available, we decided to verify once more, by employing the following analysis, the reliability of our method of using two bags at each station. Two years of fairly heavy starfish setting, 1941 and 1952, were selected and correlations between bag A and bag B were computed for each collection date on which there were at least 10 starfish

in one or more bags. For 1941 these correlations ranged from 0.58 to 0.97; for the year 1952, from 0.59 to 0.98. The over-all average correlation was 0.88 and the estimated reliability, based upon data from both bags, was 0.94. This is a highly satisfactory reliability figure indicating, therefore, that even during times when at some stations one of the two bags was lost, our results on the intensity of setting for that period based on examination of only one bag were still reliable.

In those instances when at some stations both bags were lost due to severe storms or because the floats indicating the position of the bags were cut off by the propeller of a passing boat, the figures of the intensity of setting for the elapsed period for those stations were arrived at by averaging the number of set at the two nearest stations.

RESULTS

According to Mead (1901) the height of the spawning season of *A. forbesi* in Narragansett Bay took place between June 4 and June 16. By the end of June many starfish in that area had extruded most of their spawn but, nevertheless, individuals with apparently undischarged gonads were occasionally found even in July. Agassiz (1877) stated that *A. forbesi* of northern waters began to spawn only during the last part of July. Coe (1912) found that starfish in Long Island Sound matured their sex products in May and early June and spawned during late June. Coe, however, emphasized considerable individual variations to be found among the starfish. A closely related form, *Asterias vulgaris*, common on the Atlantic coast of Canada, spawned, according to Smith (1940), in early June. Hancock (1958), working on Essex oyster beds in England in 1954, found that *A. vulgaris* began to spawn on May 29 when the water temperature had reached 15.0° C. Another closely related species, *Asterias rubens*, began to spawn as early as April (Vevers, 1949). A more extensive review of the spawning of asteroids of the north temperate zone is offered by Hyman (1955).

Our observations on *A. forbesi* in Long Island Sound, covering the period of more than two decades, showed that, in general, they commence to spawn within a few days after the water temperature reaches approximately 15.0° C., which usually occurs around the middle of June. As observed by Mead in Narragansett Bay, our starfish usually do not discharge their entire supply of sex products within a few days but, on the contrary, some individuals spawn intermittently until the end of August and, in certain cases, spawning extends into early September.

After completion of spawning the gonads of starfish undergo the process of resorption, usually complete in October, after which active development of new sex cells begins. Gametogenesis is quite rapid during November and December and, as a result, the gonads increase considerably in size during that period. Between January and March many starfish may already be found with gonads of nearly normal size, although they are probably physiologically immature because, in most instances, the eggs obtained from the ovaries of the starfish at that time of the year could not be fertilized. However, by following our method of conditioning bivalves for spawning outside their natural period of propagation (Loosanoff and Davis, 1950), development of gonads of starfish in late winter and early spring can sometimes be accelerated.

The length of the larval period of *A. forbesi* under natural conditions has never been precisely ascertained. Our field observations and laboratory experiments indicate, nevertheless, that in early summer its length may be approximately three weeks. For example, observations made in 1937 showed that the first spawning of starfish in Long Island Sound occurred on June 16 and the first set was recorded about July 8, or approximately 22 days later. In 1938 the first spawning was observed on June 14, whereas the first setting, although very light, was noted about July 5, again approximately 21 or 22 days later. The field observations on the duration of the larval period were in agreement with the results of our laboratory experiments, where the first metamorphosing larvae in our cultures were noticed 20 or 21 days after fertilization.

It is realized that even though the period elapsing between the time of fertilization of the egg and metamorphosis of the larva was established, during our field and laboratory observations, as about 21 days, this period, as in the case of larvae of other invertebrates, for example, oysters, *Crassostrea virginica*, or clams, *Mercenaria mercenaria*, may vary considerably according to changes in the environment, such as changes in temperature or in quality or quantity of food (Loosanoff and Davis, 1963). For example, whereas larvae of *M. mercenaria* grown at a temperature of about 30° C. metamorphosed in some instances within 7 days after fertilization, larvae originating from the same parents but kept at a temperature of 18° C. required as long as 16 or even 24 days before they began to set. Thus, it is logical to assume that, while starfish larvae originating from early spawning in June, when the water temperature in Long Island Sound is normally only slightly above 15° C., require approximately three weeks to reach metamorphosis, larvae originating from eggs discharged in the middle of summer, when the temperature of 20° C. or higher prevails, may develop in half the time indicated above, especially if good food organisms needed for larval growth and development are present in optimum numbers.

Under adverse environmental conditions, such as periods of low temperature following discharge of eggs or relative sparseness of good food organisms, the larval stage may be of much longer duration. Periods of heavy rains causing reduction of salinity of the water to approximately 16–18 ppt., the lowest level at which normal development of starfish may proceed (Loosanoff, 1945), may also be responsible for prolongation of the larval period or even for complete mortality and, therefore, disappearance of starfish eggs and larvae.

Mead (1901) stated that in Narragansett Bay starfish first began to set June 28, or within a day or two of that date. He, however, did not give any figures showing intensity of setting. Mead also found that in that locality starfish set principally during the last few days of June and the first week of July, but the setting sometimes continues as late as July 16. As will be shown later, the average length of the setting period in Long Island Sound is considerably longer than that reported by Mead.

Our observations indicated that, with the exception of the year 1945, when setting began and ended within the same day, September 11, the date of beginning of setting varied in different years from the last week of June to the last week of July (Fig. 3). However, since these observations were made primarily at stations located in open Long Island Sound at depths ranging from 10 to 30 feet, it is pos-

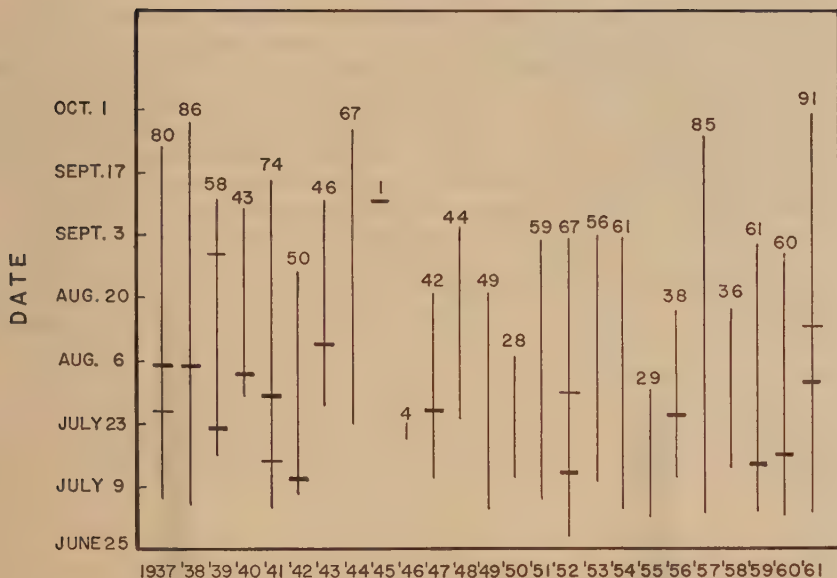


FIGURE 3. Length of setting period of starfish in different years. Cross-bars indicate the time when peaks of first and second waves of setting occurred, broader bars indicating the peaks of the heavier waves. Long Island Sound, 1937-1961. Figures at top of each bar indicate number of days in each setting period.

sible that, in some inshore, shallow, well-protected areas, where the temperature of the water is somewhat higher, scattered light setting may have preceded that of Long Island Sound proper by a day or two, a circumstance not substantially changing the basic annual picture of setting.

During the 25-year period, in almost half the years the beginning of setting occurred before July 8, while in only three years did it occur as late as the last week of July. During the remaining years, except 1945 when setting was abnormally delayed and confined to September 11 only, the beginning of setting took place between the end of the first and the beginning of the last week of July. In the years when intensity of setting was medium or heavy, the beginning of setting usually occurred within the same 24 hours at all three depths.

Setting in different years ended between July 23 and October 1 (Fig. 3). It extended into the second part of September in only five years. During four of these years setting began early and the setting period was, therefore, of long duration. The exception was 1944 when the beginning of setting was delayed until July 23.

One of the most significant observations made during these studies concerns the length of the setting period in different years. In 1945 setting began and ended within the same day. In other years its length varied from about 4 days in 1946, a year of very light setting, to 91 days in 1961 (Fig. 4). In four years setting continued for 80 days or longer. The average annual length of the setting

period was about 52 days. However, considering extensive deviations from this figure in both directions, it is given here merely as an approximation.

The earliest date for the beginning of setting was June 28, in 1952, and the latest, July 29, in 1940. Thus, even not considering the abnormal year 1945, the date for the beginning of setting of starfish in Long Island Sound differed by 31 calendar days, a rather extensive period. The end of setting in different years occurred between July 23 and October 1, covering an even longer period of approximately 70 days, thus indicating the great variations in the chronology of annual biological events involved in the propagation of starfish.

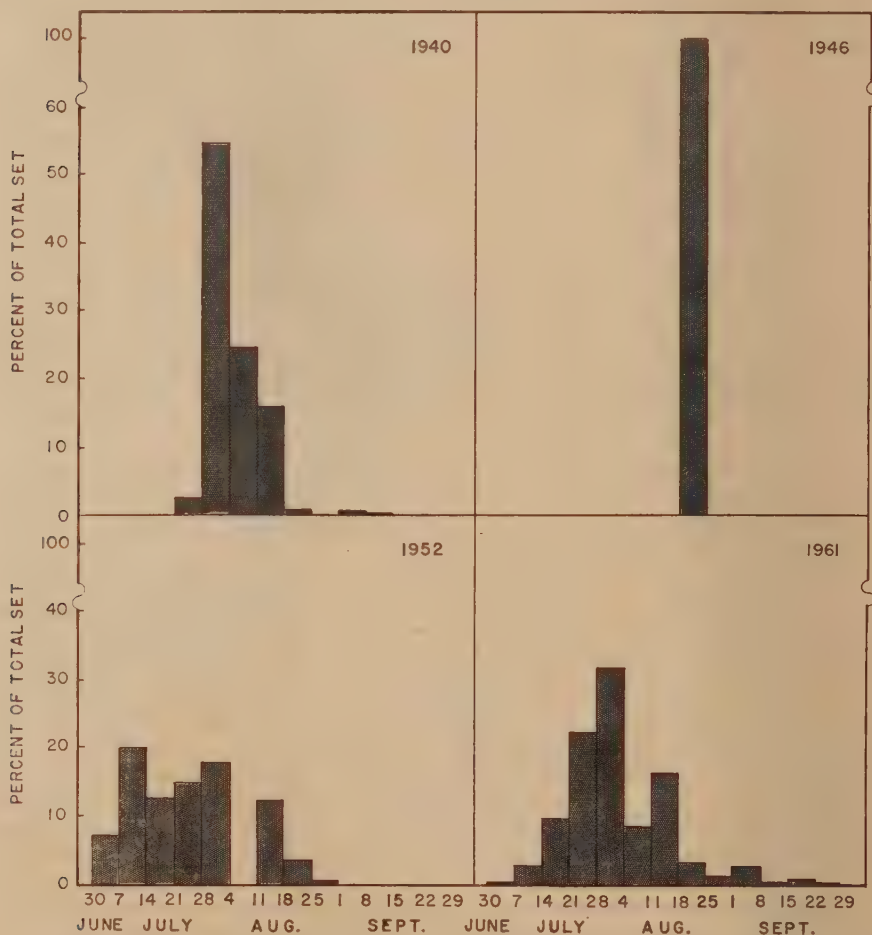


FIGURE 4. Variations in weekly intensity of starfish setting in different summers. Sometimes, as in 1946, the entire set (100%) may occur within a single week, while in other years, as 1961, when setting continues for a long time, its intensity may vary greatly from week to week.

For organisms like the American oyster, *C. virginica*, setting of which is usually relatively heavy, the date when the maximum setting of the season occurs may be ascertained with comparative ease (Loosanoff and Nomejko, 1951). In the case of starfish, however, such maxima are not always clearly defined because the intensity of setting is too light or, in some instances, too uniform to show distinct waves of setting culminated by definite peaks. In the years of heavy setting, however, not one, but two distinct waves of setting may, nevertheless, be recorded. Such quite clearly defined double waves occurred in 1937, 1939, 1941, 1952, and 1961 (Fig. 3). In three of these years the first wave was the heavier of the two, but in the remaining two, 1937 and 1941, setting began with a light wave while the second and heavier wave occurred later in the season.

Searching for signs of periodicity, or orderly patterns in the chronology of events of starfish setting, we found that the interval extending from the beginning of setting to the peak of the first wave, recorded during the 13 years when such peaks could be clearly established, varied in different years from 3 to 31 days, but showed no definite pattern. During the five years when the maxima of the first and second waves were determined, the intervals between the two peaks were

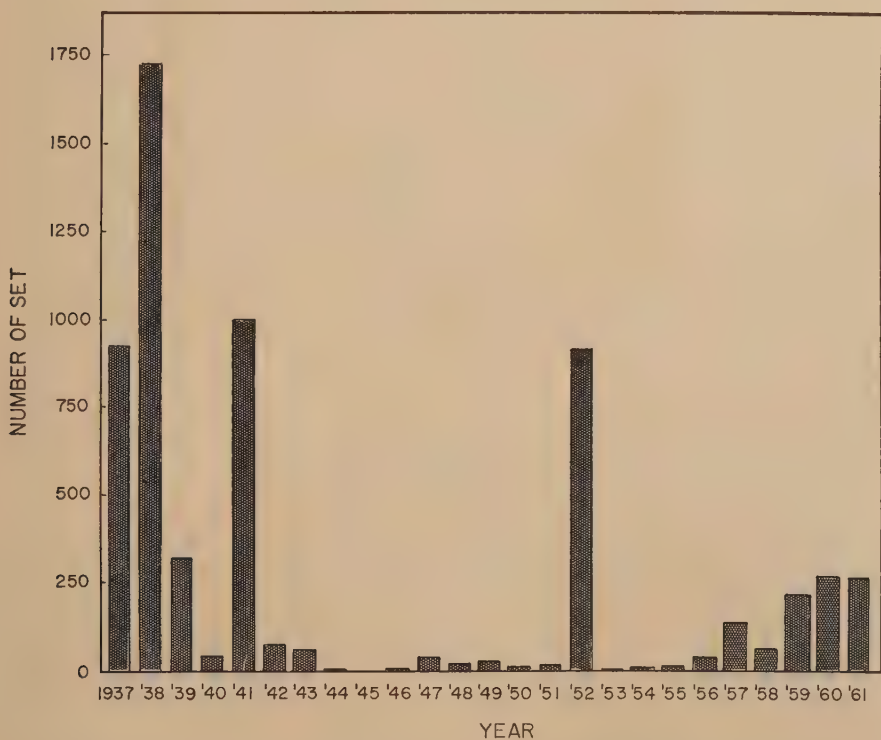


FIGURE 5. Average number of starfish set per station recorded on one hundred oyster shell-surfaces during different years. Long Island Sound, 1937-1961.

10, 39, 14, 32, and 49 days, again suggesting no periodicity. Finally, in the same five years, the beginning of the second wave occurred 30, 45, 25, 20, and 12 days after the beginning of setting, again failing to indicate any pattern.

As can be expected over such a lengthy period of observation, considerable variations in intensity of setting were recorded from year to year (Fig. 5). The rank orders of each of 25 years, based on averaging the intensity of setting each year for all the stations, regardless of their depth, and for the groups of stations located at the three different depths are given in Table I. The year 1938 ranked highest, while 1945 was lowest. Ranks of other years, as given in Table I and as shown, indirectly, in Figure 5, indicate that there was no definite succession of good and poor years. For example, the good years, such as 1941, may be preceded by a year of relatively poor setting while, on the other hand, the years of poor setting, such as 1942 and 1953, may be preceded by very good years.

TABLE I

*Yearly rank-order of intensity of starfish setting at stations of 10-, 20-, and 30-foot depths, and ranking average of all stations during each year of the 25-year period. Long Island Sound, 1937-1961**

YEAR	Rank-order of stations				YEAR	Rank-order of stations			
	10 ft.	20 ft.	30 ft.	All stations		10 ft.	20 ft.	30 ft.	All stations
1937	2	2	3	3	1950	21	16	20	20
1938	3	1	1	1	1951	22	22	17	19
1939	5	7	6	5	1952	4	3	2	4
1940	14	14	11	14	1953	25	24	24	24
1941	1	4	4	2	1954	20	21	23	22
1942	9	11	14	10	1955	19	19	19	18
1943	16	10	10	11	1956	12	18	12	13
1944	18	20	22	21	1957**	10	9	8	9
1945	24	25	25	25	1958	11	12	13	12
1946	23	23	21	23	1959	6	6	9	8
1947	15	13	15	15	1960	8	8	5	6
1948	13	17	18	17	1961	7	5	7	7
1949	17	15	16	16					

* In case of a tie, the earlier of the two years was given higher rank.

** Only stations 1, 2, and 3, all in the Milford area, were established.

Observations made during the period extending from 1944 to 1961, when the same 10 stations were used (Table II), as well as during the entire period of 25 years' study (Fig. 6), showed that, in general, during the years of heavy setting good sets were recorded at all depths. However, although the trend was not too well-marked, there was a tendency for the depths to be ranked in the following order: 30 feet—heaviest, 20 feet—medium, and 10 feet—lightest. The Bridgeport area was first, producing the heaviest sets for most of the years, while Milford and New Haven were quite consistently second and third, respectively (Table II).

Although, as mentioned earlier in this article, results of the statistical studies carried on to ascertain the presence or absence of simple or compound correlations

existing between numerous biological and ecological variables involved in propagation of starfish will be discussed in another paper, it may be appropriate here to mention briefly some of our findings that are of general interest. For example, it was determined that sets beginning early in the season may be either heavy or light, but those beginning late are usually light. Thus, all the sets that began on July 20 or later, taking place in the years 1940, 1943, 1944, 1946, and 1948, were light.

While light sets may end early in the season, heavy sets normally end fairly late. Taking the years of heavy and medium-heavy setting, which includes the years 1937, 1938, 1939, 1941, 1952, 1957, 1959, 1960, and 1961, ranking in intensity of setting from 1 to 9 during the 25-year period (Table I), we find that,

TABLE II

*Number of starfish set on 100 shell-surface at each of 10 stations as recorded in different years; rank-order of each station and each of the three areas for this period.
Long Island Sound, 1944-1961*

Areas	Milford			New Haven				Bridgeport		
Stations	1	2	3	4	5	6	7	8	9	10
Years	Numbers of starfish set									
1944	9	6	6	0	3	3	0	14	20	20
1945	0	0	0	0	0	0	0	0	0	3
1946	3	0	15	0	0	0	0	3	16	16
1947	33	60	76	0	3	6	33	18	128	67
1948	51	6	35	0	3	3	11	12	44	39
1949	15	33	79	0	0	0	16	16	62	79
1950	3	11	6	3	3	8	6	3	42	29
1951	0	5	33	0	0	0	28	12	15	29
1952	124	635	1605	19	74	357	721	1621	1597	2453
1953	0	0	3	0	0	0	0	0	3	9
1954	3	8	6	0	0	3	3	11	15	9
1955	3	12	23	3	0	6	14	21	21	34
1956	18	26	101	3	6	6	31	78	18	147
1957*	62	113	238	—	—	—	—	—	—	—
1958	85	50	65	0	0	0	0	144	191	156
1959	95	184	275	51	92	124	105	237	730	302
1960	64	200	536	88	82	164	798	102	277	379
1961	58	272	315	6	33	125	240	281	861	483
Station total	564	1508	3179	173	299	805	2006	2573	4040	4254
Station rank	8	6	3	10	9	7	5	4	2	1
Area average set per station	1750			319				3622		
Area rank	2			3				1		

* Since only stations #1, #2, and #3, all in the Milford area, were maintained in 1957, this year is not included in ranking estimates.

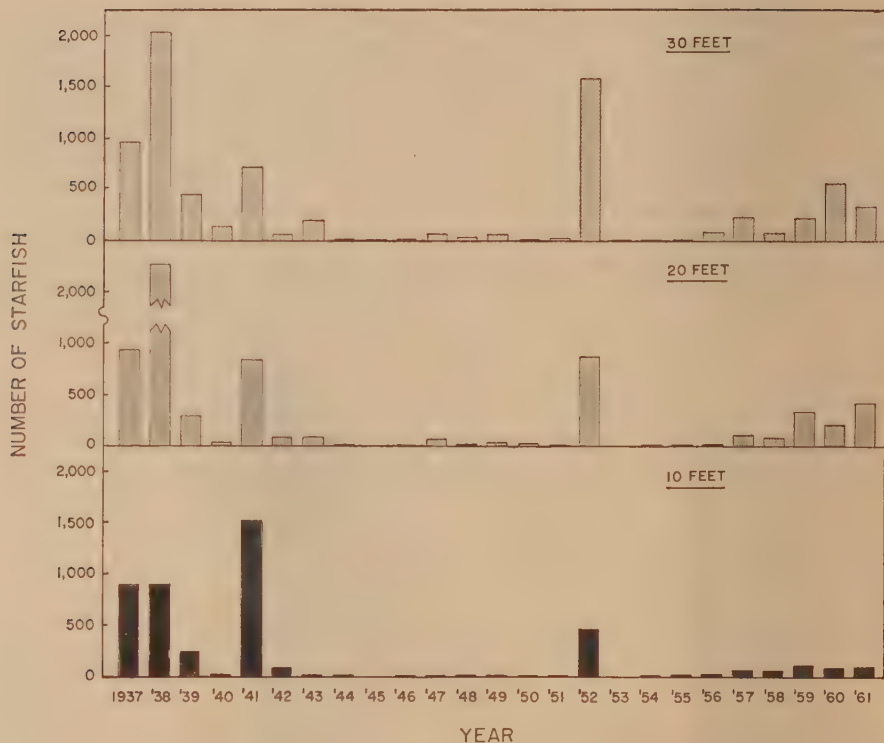


FIGURE 6. Average number of starfish set per station recorded in different years on 100 oyster shell-surfaces at stations located at 10-, 20-, and 30-foot depths. Long Island Sound, 1937-1961.

with the exception of 1960, setting during all these years extended into September. In four of these years setting continued almost until the end of September and, on one occasion, actually occurred on October 1.

Taking the ten poorest years, ranking from 16th to 25th, only in one year, 1945, did setting extend beyond the first week in September. However, in that unusual case setting began and ended on September 11. In some poor years, as in 1946, setting ended on July 23, while during another poor year, 1950, it ended on August 7. Thus, in general, during the years of heavy setting, starfish continued to set later in the season than during the years of light setting.

Heavy sets tend to be of long duration, while poor sets tend to be short. During the nine years of heavy sets the setting period ranged from 58 to 91 days, averaging about 74 days. The length of the period during the ten poorest years, however, ranged from 1 to 67 days and averaged only about 40 days.

A setting which reached a maximum, or peak, early in the season may end early or fairly late, while a setting that reached a maximum late tends to end late in the season. This tendency, however, was not too well-defined because in some

years, for example, 1944 (Fig. 3), setting continued as late as September 27, even though no definite peaks or waves were manifested.

During the period of 17 years, from 1940 to 1956, Milford Laboratory conducted regular, semi-annual surveys on the distribution and occurrence of adult starfish over the oyster-producing grounds located along the Connecticut shore between Branford and Black Rock, west of Bridgeport Harbor. Uniform methods were used throughout the period, and the dredging was done along the same lines. Results of these surveys were reported in bulletins issued by our laboratory for the information of members of the Connecticut and New York oyster industries. The reports were accompanied by maps showing the lines of the surveys and the numbers of starfish found along these lines. In preparation of this article it was decided to use these data to compare the intensity of starfish setting in different years with the numbers of adult starfish recorded during the spring surveys, the time corresponding to the pre-spawning period. The relative abun-

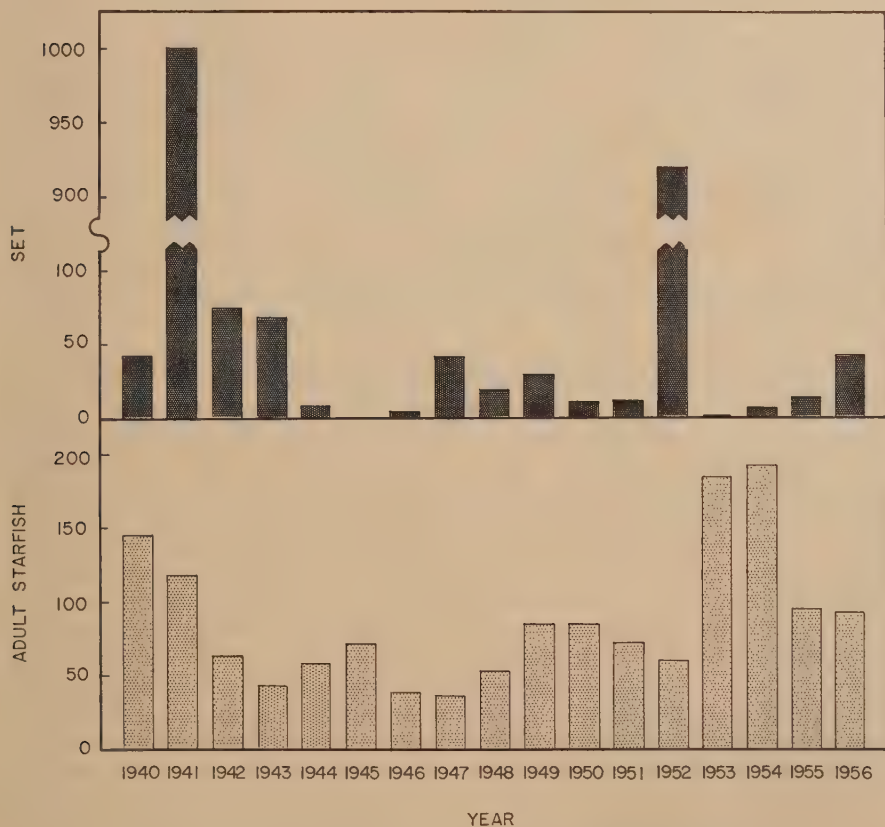


FIGURE 7. Comparison between numbers of adult starfish and starfish set in different years. Long Island Sound, 1940-1956.

dance of adult starfish was based on the average number of these echinoderms per 10,000 feet of dredging. This approach was shown statistically to be the most reliable measure, as compared to others, such as average number of starfish per 10-minute drag, etc.

As has already been shown, there was considerable variability in the numbers of starfish set in different years, with only two good years recorded during the period extending from 1940 until 1956 (Fig. 7). The numbers of adult starfish, recorded in different years during the same period, showed much less variability. In general, the comparison indicated no appreciable relationship between numbers of adult starfish existing during pre-spawning periods and intensity of starfish setting later in the season. For example, while a heavy set of starfish in 1941 was preceded by a spring showing a high adult population, the other season of heavy setting, 1952, was characterized by relatively low numbers of adults. Moreover, even though in 1953 and 1954 the numbers of adult starfish recorded were the highest during the period of observations, the starfish sets during these two years were among the lowest on record (Fig. 7).

It is also of considerable biological interest that, regardless of a very heavy starfish set in 1941, the adult population of starfish in 1942 showed almost a 50% decrease, instead of a normally anticipated increase. We have already reported that, similar to the observations described in this article, we found no relationship between the number of adult oysters and intensity of oyster setting in Long Island Sound (Loosanoff *et al.*, 1955).

Burkenroad (1946), basing his conclusions chiefly on newspaper notes and conversations with oyster growers, concluded that the starfish has been particularly destructive to the oysters of Long Island Sound at intervals of about 14 years. According to him such peaks of population have occurred in 1900, 1914, 1928, and 1942. Adding 14 years to the last figure the year 1956 should then be another year of population peak. Our data show, nevertheless, that neither 1942 nor 1956 was a year of good starfish setting (Figs. 5 and 7). They ranked only number 10 and number 13, respectively, thus being about average years (Table I). Therefore, our observations on intensity of setting do not support Burkenroad's contention. It is realized, nevertheless, that as we have just mentioned, the increases in numbers of adult starfish in Long Island Sound are not proportional to the numbers of set because, as is often the case in such forms as starfish and oysters, a heavy set may perish within a few days or weeks after its occurrence, thus contributing nothing to the increase of the adult population; while, in other years, a relatively light set that survives well may considerably increase the numbers of adults.

We may add to the above discussion that our field studies show that neither of the years 1942 or 1956 was characterized by large populations of adult starfish (Fig. 7). Furthermore, the year of 1949, which according to Burkenroad's estimates should have been the year when adult starfish were least numerous, was in reality a year of larger population than the year of 1942 and of only somewhat smaller population than the year of 1956. Coe (1956), discussing fluctuations in populations of marine invertebrates, also doubts that the data collected and presented by Burkenroad were sufficient to justify the conclusion that definite periodic cycles in starfish population actually prevail.

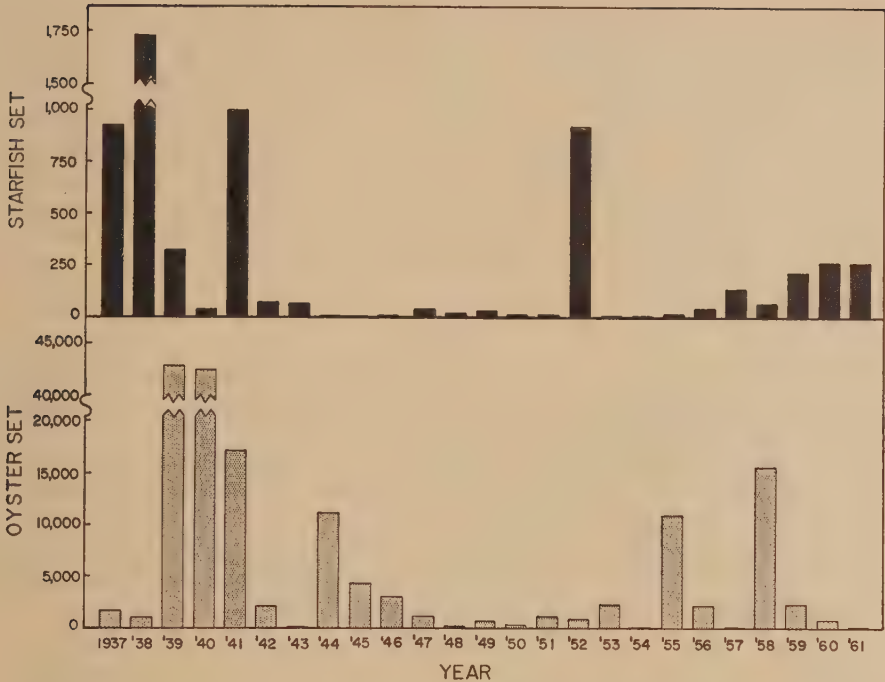


FIGURE 8. Average numbers of oyster and starfish set per station recorded in different years on 100 oyster shell-surfaces. Long Island Sound, 1937-1961.

Loosanoff *et al.* (1955) have shown that during the 18-year period, 1937-1954, no definite relationship was found between intensity of starfish and oyster setting in Long Island Sound. After carrying on these studies for an additional seven years, until 1961, the conclusion remained the same (Fig. 8). As in the past, we believe that the differences in intensity of setting of starfish and oyster larvae in the same years are principally due to causes of a specific nature, such as different food requirements of the larvae of the two animals and mortality caused by specific diseases and parasites of the larvae.

Still another factor to be considered in connection with mortality of larvae is the frequent presence in the water of certain external metabolites, the ectocrines, produced by many forms, including certain dinoflagellates, which may seriously affect the larval population of one species without affecting others. We hope that, because of recent advances in the technique of cultivation of eggs and larvae of marine invertebrates, which now permit conducting experiments on various aspects of behavior of these organisms and on the effects of natural and synthetic chemical compounds upon growth and survival of larval forms, many of these matters will be resolved in the near future.

During the quarter of a century when these studies were conducted many people contributed directly or indirectly to their success. I am grateful to them all, espe-

cially to my former aides, Messrs. Charles A. Nomejko, James B. Engle and John Malarkey, who spent countless hours examining the collectors and counting starfish set, and to Messrs. Joseph F. Lucash and Herman R. Glas, captains of our research boats, who, regardless of the weather, attended the stations in Long Island Sound to change and bring back the collectors, thereby making it possible to maintain these studies on a systematic basis. To Mrs. Susan Webb I am under obligation for preparing the illustrations, as well as for other help in completion of the manuscript, and to Miss Rita Riccio, Dr. James Hanks, and Mr. Harry C. Davis, for their helpful editorial suggestions. To Mrs. Barbara Myers I am obliged for the statistical analysis of the data.

SUMMARY

1. Setting of starfish (*A. forbesi*) was recorded at all depths of Long Island Sound from several feet above mean low water mark to 100 feet. No systematic observations were made at greater depth.

2. Starfish commence spawning when water temperature reaches approximately 15° C., which usually occurs about the middle of June. In some individuals spawning may continue into early September.

3. With the exception of 1945, when setting began and ended within the same day, September 11, the date of beginning of setting during the 25-year period varied from the last week of June to the last week of July.

4. The end of setting in the different years occurred between July 23 and October 1. In only 5 years setting continued into the second part of September.

5. The length of the setting period varied from one day, in 1945, to 91 days in 1961. In four years setting continued for 80 days or longer, but the average annual length of the setting period was about 52 days.

6. Intervals extending from the beginning of setting to the peak of the first or second waves of setting, and the time relationship between the first and second waves of setting did not show any orderly pattern.

7. During the 25-year period of observations the year 1938 held the highest rank in numbers of starfish set, while the year 1945 was the lowest. In general, the ranking indicated that there was no definite succession of good and poor years.

8. During the period of 17 years, 1940-1956, no appreciable relationship was found between numbers of adult starfish present during the pre-spawning period and intensity of starfish setting later in the season.

9. Our observations do not support the contention that peaks of the adult starfish population in Long Island Sound should have occurred in 1942 and in 1956.

10. No definite relationship was found between the intensity of starfish and oyster setting in Long Island Sound.

11. Larval diseases of specific nature, caused by various microorganisms, quality and quantity of food available, and the presence in the water of various ectocrines, may be principally responsible for the survival or mortality of starfish larvae and, therefore, for variations in intensity of setting of starfish in different years.

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**Chronic Exposure of Spot, *Leiostomus xanthurus*, to Sublethal
Concentrations of Toxaphene in Seawater**

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INTRODUCTION

Both laboratory and field experiments have shown the chlorinated hydrocarbon insecticides to be acutely toxic to fish (Harrington and Bidlingmayer, 1958; Henderson, Pickering, and Tarzwell, 1959; Workman and Neuhold, 1963). However, relatively few studies have been conducted to determine the chronic effects of these chemicals on fish and other aquatic organisms. One exception is the excellent work of Mount (1962) on the chronic effects of endrin to bluntnose minnows and guppies.

The present laboratory study was undertaken to determine the effects of prolonged exposure of juvenile spot, *Leiostomus xanthurus*, to sublethal concentrations of toxaphene in seawater. The spot is a commercially important sciaenid which spends much of its life in the inshore waters of the Atlantic and Gulf coasts. Toxaphene ($C_{10}H_{10}Cl_8$), a chlorinated camphene insecticide, was selected because it is used extensively on cotton and other agricultural crops in the southeastern United States and might possibly reach estuarine waters.

MATERIALS AND METHODS

This study was conducted at the Bureau of Commercial Fisheries Biological Laboratory, Gulf Breeze, Florida between 15 January and 15 June 1963. The laboratory salt water supply is pumped directly and continuously from the relatively clear waters of Santa Rosa Sound in northwest Florida. The toxicity tests were set up with a constant-flow system in which test solutions were renewed continually. This system eliminated the need for aeration and assured a steady concentration of the toxicant.

The fish were held in plastic¹ aquaria with

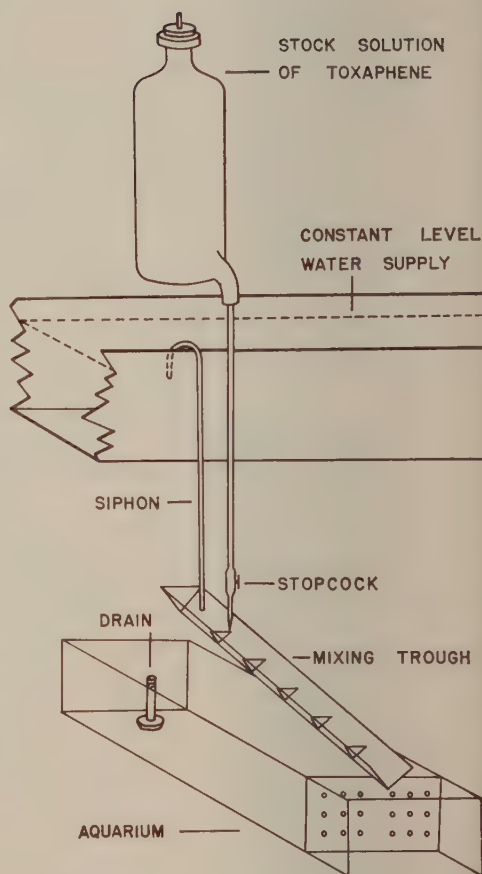


FIGURE 1.—Diagram of constant-flow apparatus.

a capacity of approximately 25 liters. Seawater passed through the aquaria at a constant rate of 154 liters per hour. Figure 1 shows the mechanism by which the water was siphoned through a plastic tube from a constant level water supply into the aquarium.

No attempt was made to control temperature and salinity of the seawater flowing through the aquaria. Average monthly water temperatures during the 5-month experiment varied from 11° C in January to 28° C in June. Minimum and maximum temperatures during this period were 7° C and 32° C, re-

¹ Plexiglas, a product of Rohm and Haas Company.

TABLE 1.—*Acute toxicity of toxaphene to spot, Leiostomus xanthurus*

Concentration of toxaphene ppb (micrograms/liter)	Number of fish tested	Number dead in:					
		24 hours	48 hours	72 hours	96 hours	120 hours	144 hours
7.5	10	10					
5.6	10	10					
3.2	10	10					
1.8	10	3	10				
1.0	10	0	5				
0.5	10	0	0	0	0	3	5
0.0 (control)	10	0	0	0	0	0	0

spectively. Average monthly salinities varied from 21 to 28 parts per thousand. Salinity extremes were 16 and 31 parts per thousand.

The toxaphene used was technical grade material supplied through the courtesy of Hercules Powder Company. Acetone stock solutions of the toxaphene were mixed in 10-liter aspirator bottles and added to the constant flow of seawater at a rate of 1 ml per minute to obtain the desired concentration. KERN-EXELO flat stopcocks² were used to meter the stock solution. These ground glass stopcocks delivered a precise amount of toxicant, but required daily adjustment to compensate for decreasing pressure as the stock bottle emptied. A V-shaped trough with baffles facilitated mixing of the toxicant with the seawater before it entered the aquarium (Figure 1).

The spot used in the experiment were seined from local waters in December 1962 and acclimated in the laboratory for 3 weeks. I estimated these fish to be approximately 1 month old when captured. Fifty fish with a mean total length of 20 mm were placed in each of four running-water aquaria.

The fish were fed daily on a mixture of ground fish, oyster meat, and a fish food supplement, Liv.³ A limited amount of natural food in the form of plankton was brought into the aquaria with the flow of seawater. The captive spot quickly learned to feed at the surface when food was placed in the aquaria. Excess or stale food was removed daily. The plastic aquaria required considerable attention to prevent fouling by oysters, barnacles, and other sessile marine organisms.

A series of short-term acute-toxicity experiments were conducted to determine toxaphene concentrations sublethal to the test species. Using the equipment previously described, and bioassay techniques similar to those described by Doudoroff *et al.* (1951), juvenile spot were exposed to a series of experimental concentrations of toxaphene in flowing seawater. Results of these tests are summarized in Table 1.

The concentrations of toxaphene used in the chronic experiment were selected on the basis of results obtained from the acute toxicity tests. Since 0.5 parts per billion (ppb) caused mortality after 5 days of exposure, concentrations of 0.1 and 0.01 ppb were chosen as initial test solutions. These concentrations proved to be below the lethal level and were maintained throughout the 5-month exposure period. Groups of control fish were maintained along with the experimentals.

Fish surviving the chronic exposure were subjected to concentrations of 0.5, 1.0, 2.0, and 3.0 ppb to determine whether there was any acquired resistance to toxaphene.

At the end of the chronic experiment samples of fish were fixed in Bouin's solution for histopathological examination. Other samples were frozen for subsequent chemical residue analysis.

RESULTS AND DISCUSSION

Mortality and growth

During 5 months of exposure to the sublethal concentrations of toxaphene there was no significant difference in mortality among control and experimental fish (approximately 15 per cent in all groups). The fish fed readily throughout the experiment and exhibited no symptoms of distress.

² Purchased from Will Scientific, Inc.

³ A product of Farm and Wildlife Products, Inc., Omaha, Nebraska.

TABLE 2.—*Acute toxicity of toxaphene to treated and untreated spot*

Source of fish	Number of fish tested	Concentration of toxaphene (ppb)	Number dead in:	
			24 hours	48 hours
Control fish from chronic experiment	5	3.0	4	4
	5	2.0	3	5
	5	1.0	0	1
	5	0.5	0	0
	5	0.0 (control)	0	0
Fish from 0.01 ppb toxaphene test	5	3.0	4	5
	5	2.0	1	5
	5	1.0	0	2
	5	0.5	0	0
	5	0.0 (control)	0	0
Fish from 0.1 ppb toxaphene test	5	3.0	5	5
	5	2.0	5	5
	5	1.0	0	3
	5	0.5	0	0
	5	0.0 (control)	0	0

Mean total lengths of the fish at the end of the experiment were approximately the same for all groups. Measurements were as follows: Controls, 63 mm; 0.01 ppb toxaphene, 66 mm; 0.1 ppb toxaphene, 64 mm. This growth rate is comparable to that of wild populations. Dawson (1958)⁴ reports that young-of-the-year spot in South Carolina are represented in the April catch at a modal length of 55 mm.

Bioassays to determine acquired resistance

Acute-toxicity tests were conducted at the end of the experiment to determine whether or not the prolonged exposure to sublethal concentrations of toxaphene had affected the resistance of the fish to this insecticide. Although the number of fish tested was small, the treated fish appeared to be even more sensitive than the control fish. Fish from each experimental group and control were exposed for 48 hours to 0.5, 1.0, 2.0, and 3.0 ppb of toxaphene in flowing seawater. Results are shown in Table 2. There was 100 per cent mortality in all groups at 2.0 ppb and no mortality at 0.5 ppb. Exposure to 1.0 ppb caused 20 per cent mortality to fish from the control group, while fish from the 0.01 and 0.1 ppb tests suffered 40 and 60 per cent mortality, respectively. Temperature and salinity of the seawater averaged 29° C and 30 parts per thousand during the 48-hour test period.

⁴Dawson, C. E. (1958) A study of the biology and life history of the spot, *Leiostomus xanthurus* Lacépède, with special reference to South Carolina. Bears Bluff Laboratories, Wadmalaw Island, South Carolina, Bulletin No. 28.

This lack of acquired resistance is contrary to the report by King (1962) that guppies (*Lebistes reticulatus*) acquired increasing resistance upon exposure to sublethal concentrations of DDT. From preliminary work conducted at our laboratory young spot appear to develop some resistance to dieldrin upon prolonged exposure to this insecticide.

The fact that the spot did not develop resistance to toxaphene does not rule out the fact that genetically resistant individuals might occur in a natural population. Ferguson (1963) reported that a small percentage of individuals in fish populations of the Mississippi Delta apparently possess some sort of genetic mechanism enabling them to survive exposure to pesticides and produce a larger proportion of succeeding generations.

Residue analysis

Specimens from the chronic experiments were analyzed by paper chromatography to determine possible accumulation of toxaphene in the bodies of the fish. These whole-body analyses revealed no toxaphene; due to the small size of the sample, residues below 0.23 ppm (milligrams/kilogram) would not have been detected by this method of analysis.

Histopathological examination of fish

Five fish from the 0.1 ppb concentration of toxaphene and five from the control were examined by Dr. Edward Wood, consulting pathologist, to identify possible internal pathological changes. The following excerpt is taken from Dr. Wood's report.

The gills show a distinct thickening of the individual lamellae with a resultant clubbing that I do not believe is artifactual. The control fish, in contrast, have slender delicate lamellae with a gossamer epithelial covering over the individual capillaries. The control and treated fish may be identified on the basis of the gill changes alone.

I suspect that true degenerative changes are present in the livers of the treated fish, but in view of the poor fixation, I am reluctant to actually describe them as toxic lesions.

Fixation of the nervous tissue was generally quite good and to a lesser degree the renal tissue was not too bad. Neither organ system demonstrated clear cut differences between control and treated fish.

The changes seen in the gills of these fish are consistent with what we have observed in toxaphene treated trout. In view of the small number and the fixation problems, I believe you should regard these results as entirely preliminary.

ACKNOWLEDGMENTS

I wish to thank Alan J. Rick of the Gulf Breeze Biological Laboratory for assistance in conducting bioassays and construction of test equipment. Appreciation is also expressed to Alfred J. Wilson, Jr. of the same laboratory for conducting the residue analyses, and to Dr. Philip A. Butler, laboratory director, for valuable advice and suggestions.

Histopathological examination of the fish was made, on a consultant basis, by Dr. Edward M. Wood, pathologist at the Tacoma Washington Medical Center.

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Landings, Fishing Effort, and Apparent Abundance in the Yellowtail Flounder Fishery

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Abstract

Otter-trawl exploitation of yellowtail flounder, *Limanda ferruginea* (Storer), on fishing grounds off New England began in the 1930's. Yellowtail are fished on three New England grounds: the southern New England ground (south of Massachusetts and Rhode Island), Georges Bank, and the Cape Cod ground (east and north of Cape Cod). The southern New England ground and Georges Bank have supplied most of the catch.

Landings have varied widely, rising to 68 million pounds (31,000 metric tons) in 1942, dropping to 13 million pounds (5,900 metric tons) in 1954, and rising again to 39 million pounds (17,700 metric tons) in 1961. An analysis of landings per day of fishing effort in 1943-61, calculated for New Bedford, Massachusetts vessels for each ground as a measure of relative apparent abundance, indicated that the pattern of apparent abundance generally was similar to that of landings. A comparison of total fishing effort with apparent abundance suggested that, following initial exploitation, apparent abundance varied independently of the effort level. The patterns of relative apparent abundance on the three grounds from 1949 to 1961 were similar.

A comparison between winter water temperature and landings per day suggested that there was an inverse relationship between temperature and apparent abundance.

Introduction

The yellowtail flounder, *Limanda ferruginea* (Storer), is the most important of New England commercial flatfishes. Landings of 39 million pounds (17,700 metric tons) by United States otter trawlers in 1961 were worth 3 million dollars to fishermen. The fishery is of comparatively recent development with active exploitation of the stocks beginning in the mid-1930's. The catch rose rapidly in the early years of the fishery,

reaching a peak in 1942. Following this, it declined sharply, dropping to a low in 1954. Recent landings, 1957-61, have shown a marked increase.

The biology and population dynamics of yellowtail from the fishing ground off southern New England were studied in the early 1940's by Royce, Buller, and Premetz (1959). They assembled information on landings, fishing effort, and landings per day of fishing for the period 1942-49. They concluded from these data, and data on the size and age composition of the catch, that the major changes occurring in the fishery during the period of study resulted from natural fluctuations in abundance and availability rather than from overfishing. They cited evidence of faunal changes which they suggested may have been partly responsible for these fluctuations.

This present report results from a continuation and expansion of the abundance study of Royce and his co-workers. The development of the yellowtail fishery is traced, and an analysis of landings, fishing effort, and average landings per day of fishing for the three principal New England yellowtail fishing grounds for the period 1943-61 is given. Landings data were obtained from statistical digests issued by the Bureau of Commercial Fisheries and from the work cited above. Data for calculation of fishing effort and average landings per day of fishing effort, as a measure of apparent abundance, were obtained from fishing trip weighout schedules and vessel interviews for the port of New Bedford, Massachusetts.

Historical Information

While yellowtail flounder frequently were caught in otter trawls before 1935, they rarely were landed in quantity because of a market preference for thicker-bodied flatfish such as winter flounder, *Pseudopleuronectes americanus*, and summer flounder, *Paralichthys dentatus*, (Royce, *et al.*, 1959). A decline during the 1930's in the abundance of winter flounder (Perlmutter, 1947), which

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until then had made up most of the total flatfish catch, led fishermen to seek other species. More intensive exploitation of the abundant yellowtail began at this time and the fishery grew rapidly, with total landings rising to more than 68 million pounds (31,000 metric tons) in 1942.

1. Fishing Gear and Methods

All yellowtail are caught by otter trawlers, with vessels of 45 to 75 feet (14 to 23 m) in length landing most of the catch. Size of trawl nets used varies with vessel size and power, footropes being about 60 to 80 feet (18 to 24 m) in length. Vigneron-Dahl gear is used. During the early years of the fishery the nets were made of cotton twine, but since the end of World War II most fishermen have changed to nylon. Mesh size of codends has varied; in the early 1960's it commonly was $4\frac{1}{2}$ inches (114 mm) stretched measure. Aside from small refinements, there have been no significant changes in gear since the late 1930's when Vigneron-Dahl gear came into widespread use.

A profitable catch for a yellowtail trip consists of about 10 to 20 thousand pounds (4.5 to 9.1 metric tons) for small draggers carrying 4 or 5 man crews. For larger vessels, carrying 6 or 8 men, it varies from 25 to 50 thousand pounds (11.3 to 22.7 metric tons). What constitutes a good trip is, of course, largely dependent upon price.

Trip length varies from 1 to 8 days depending on boat size, distance to ground, weather, fishing success, and fish price. The trawl is towed for about 2 hours for each set, and fishing operations are carried on day and night.

There is no yellowtail fleet in the same sense as there are haddock and redfish fleets which seek a particular species on a year-round basis. Fishermen fishing for yellowtail in the fall may change to summer flounder fishing in the winter months, when summer flounder are concentrated on offshore grounds, and to inshore winter flounder fishing in the spring. Sometimes fishermen fish for other species during a part of a yellowtail trip. Some vessels are converted to sea scallop dragging when yellowtail are scarce; they are reconverted to otter trawling when this again becomes more profitable. Some yellowtail fishermen join the industrial fishery in the spring and

summer months when the abundance of industrial species, used for fish meal, is highest. All of these conditions prevent clear identification of a yellowtail fleet.

2. Fishing Grounds

Yellowtail inhabit Atlantic coastal waters from the Gulf of St. Lawrence and the Newfoundland banks southward to Chesapeake Bay (Bigelow and Schroeder, 1953). They are found in water as shoal as 5 fathoms (9 m) during winter months and in cold, deeper water in summer. They are usually caught in 20 to 35 fathoms (37 to 64 m) of water, however, and mostly over sandy bottoms. The species is fished commercially on grounds off New England, which supply most of the catch, and on fishing banks southeast of Nova Scotia.

Yellowtail fishing areas off New England are the ones principally considered here, and these have been divided into three major grounds based on results of marking experiments and other studies (Royce, *et al.*, 1959; Lux, 1963). The three grounds, defined in terms of the northwest Atlantic statistical units established for reporting catch by area (Fig. 1), are as follows²:

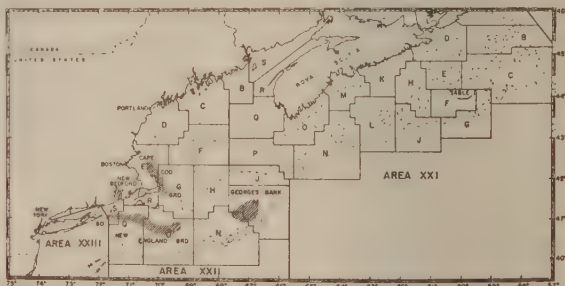


Fig. 1. Principal fishing grounds off New England and areas (shaded) where most yellowtail are caught. (The statistical areas are those defined by Rounsefell, 1948.)

Southern New England ground. This ground includes the area from south of Nantucket to south of Long Island. It is made up of subareas XXII O, Q, R, and S, and area XXIII. Yellowtail are caught between the 20 and 30 fathom (37 to 55 m) curves. Most of the catch is from subareas O and Q and is taken from fall to early spring.

²The subareas shown in Fig. 1 were used here for designating grounds because these are the statistical units by which United States landings are reported (Rounsefell, 1948). ICNAF subarea 4 is the equivalent of area XXI, and ICNAF subarea 5 is the equivalent of area XXII. Area XXIII, being outside of the convention area, has no ICNAF equivalent.

Georges Bank. This ground includes subareas XXII H, J, M, and N. Most of the yellowtail are caught between the 25 and 35 fathom (46 to 64 m) curves here. The catch is highest from subareas M and N, taken mainly in the summer and fall.

Cape Cod ground. This ground includes areas along the eastern shore of Cape Cod, Cape Cod Bay, Stellwagen Bank, and shoal waters around Cape Ann, off Gloucester, Massachusetts. The ground is included in subareas XXII E and G, and yellowtail landings reported for these subareas are considered to have come from this ground. Most yellowtail are caught here between the 5 and 35 fathom (9 to 64 m) curves and are taken principally from late fall to spring.

In addition to catches from these three major grounds, small quantities of yellowtail are taken off the Maine coast. These landings have been grouped under the heading "Northern Gulf of Maine," subareas XXII B, C, D, and F, in later discussion.

Results of tagging on each of the three major grounds showed that considerable movement, usually seasonal in nature, occurred within grounds, but that the amount of mixing between grounds was small. The movement patterns within each ground are given by Royce, *et al.* (1959) and Lux (1963). The extent of mixing is summarized below.

Of 2,945 yellowtail tagged on the southern New England ground in 1955, 1957, and 1959, there were 532 returns for which recovery ground was given. Of these, 513 were recaught on the southern New England ground, 14 on Georges Bank, and 4 on the Cape Cod ground.

Of 430 yellowtail tagged on Georges Bank in 1957, there were 119 returns for which recovery ground was given. Of these, 114 were recaught on Georges Bank and 5 on the southern New England ground.

Of 1,585 yellowtail tagged on the Cape Cod ground in 1957 and 1959, there were 268 returns for which recovery ground was given. Of these 265 were recaught on the Cape Cod ground, 2 on the southern New England ground, and 1 on Georges Bank.

The above results indicated that yellowtail on each ground were relatively separate from

those on other grounds. This geographic separation of yellowtail was supported by information on occurrence of parasitized fish (Lux, 1963). About 35 per cent of the yellowtail from samples taken on the Cape Cod ground were infested with metacercariae of the trematode, *Cryptocotyle lingua*, although samples from the other two grounds were uninfested. Fin ray counts of yellowtail from the three grounds showed no differences, suggesting that if there were distinguishing features in fish from each ground they were small.

On the basis of the preceding data, a separate group of yellowtail was tentatively recognized on each of the three grounds. Each group was treated individually for the analysis dealt with here.

The fishery for yellowtail on the Nova Scotian banks is primarily a Canadian one, but United States vessels have made occasional trips to these distant grounds at times when fish were abundant there and the price was high. Most of the United States catch was taken near Sable Island (Fig. 1). Nova Scotian yellowtail apparently are of a completely distinct group from those caught off New England, for they differ from them in fin ray numbers and body proportions (Scott, 1954).

3. Ports of Landing

Yellowtail are landed at ports from New Jersey to Maine but currently most of the catch is landed in Massachusetts and Rhode Island (Table 1). Ports in Connecticut, New York, and New Jersey received moderate amounts of fish during the late 1930's and through the 1940's, but their importance has declined in subsequent years.

By 1940 New Bedford, Massachusetts had become the principal yellowtail port because of its previously established facilities and its proximity to the fishing grounds. In all years following 1940 one half or more of the total yellowtail catch has been landed there. Yellowtail landings there in 1961 of 30 million pounds (13,600 metric tons) made up about 75 per cent of total landings of this species. Other ports of importance are Provincetown and Woods Hole, Massachusetts and Point Judith and Newport, Rhode Island³. Their combined 1961 landings totaled about 5 million pounds (2,300 metric tons).

³Quantities landed at Woods Hole since 1961 have been insignificant.

TABLE 1. Annual United States landings of yellowtail flounder in New England States and in New York and New Jersey, 1938-61. (Landings 1938-45 are from data compiled by Royce *et al.* (1959). Landings for subsequent years are from Bureau of Commercial Fisheries annual statistical digests). (In thousands of pounds; 1 metric ton = 2,205 pounds)

Year	Maine	Massachusetts	Rhode Island	Connecticut	New York & New Jersey	Total
1938	301	16,985	364	1,781	3,384	22,815
1939	222	20,662	397	3,129	4,316	28,726
1940	827	28,352	1,059	4,090	6,544	40,872
1941	276	37,912	334	4,246	8,921	51,689
1942	26	47,932	2,420	6,193	12,007	68,578
1943	46	32,897	2,052	3,605	7,187	45,787
1944	127	19,283	3,027	3,187	5,518	31,142
1945	73	24,358	2,852	2,801	3,085	33,169
1946	37	23,709	2,240	3,171	2,311	31,468
1947	91	27,630	2,259	3,006	3,333	36,319
1948	118	32,087	3,293	1,352	2,778	39,628
1949	120	25,409	1,138	550	1,519	28,736
1950	145	21,399	1,029	302	1,241	24,116
1951	82	16,735	723	100	774	18,414
1952	55	15,306	1,334	49	234	16,978
1953	58	12,627	1,014	24	50	13,773
1954	24	10,972	1,681	30	56	12,763
1955	30	12,661	1,448	60	174	14,373
1956	52	11,756	2,444	161	230	14,643
1957	41	19,910	2,230	91	179	22,451
1958	64	29,519	2,984	226	532	33,325
1959	113	25,932	3,012	139	615	29,811
1960	65	27,701	2,110	160	1,171	31,207
1961	34	34,667	2,338	107	2,082	39,228

TABLE 2. Yellowtail landings by fishing ground, 1942-61. Landings were calculated for each ground from vessel interviews, log book data, and published statistics of the Bureau of Commercial Fisheries. Landings 1942-49 were taken from Royce *et al.*, (1959). (In thousands of pounds; 1 metric ton = 2,205 pounds).

Year	Southern New England Ground	Georges Bank	Cape Cod Ground	Northern Gulf of Maine	Nova Scotian Banks	Total
1942	62,797	2,385	3,330	26	40	68,578
1943	39,777	2,784	2,831	74	321	45,787
1944	23,406	3,670	3,335	68	608	31,087
1945	22,862	2,990	2,554	30	4,733	33,169
1946	23,867	1,913	2,774	30	2,737	31,321
1947	26,706	4,976	2,387	49	1,636	35,754
1948	21,872	12,472	1,464	23	3,137	38,968
1949	10,305	16,097	2,711	46	651	29,810
1950	10,384	8,581	2,974	192	1,969	24,100
1951	6,144	9,505	1,858	137	770	18,414
1952	6,591	8,051	1,714	81	520	16,957
1953	4,358	6,389	1,705	89	1,225	13,766
1954	3,340	6,364	2,469	30	560	12,763
1955	4,807	6,495	2,874	45	152	14,373
1956	7,809	3,515	3,245	58	16	14,643
1957	11,996	5,074	5,196	57	123	22,446
1958	19,637	9,995	3,555	87	42	33,316
1959	17,060	9,106	3,365	140	122	29,793
1960	17,293	9,804	3,996	86	28	31,207
1961	25,645	9,365	4,145	49	24	39,228

Relative Importance of Grounds

Yellowtail landings, recorded separately since 1938, have varied widely during the short life of the fishery (Table 1). They rose rapidly to a peak of 68 million pounds (31,000 metric tons) in 1942, declined to a low of 13 million pounds (5,900 metric tons) in 1954, and increased substantially again in recent years.

Landings by fishing ground for 1942-61, based on vessel interview data, are given in Table 2. The southern New England ground has generally provided most of the catch, with the importance of Georges Bank increasing sharply after 1947. Landings from the Cape Cod ground were smaller, and showed less year to year fluctuation, than those from the previous two grounds. Information from vessel interviews and trip weightout schedules indicates that yellowtail landings from the northern Gulf of Maine subareas were principally caught incidentally to other fish. These data are of importance primarily in that they show the scarcity of yellowtail there. Landings from Nova Scotian banks contributed little to the total catch except during the late 1940's. They cannot be considered indicative of yellowtail abundance on these grounds, because New England fishermen fished there sporadically.

1. Methods

Interviews of New Bedford vessel captains, upon return to port, for information on catch, grounds, and time fished have been obtained since October 1942. Average yellowtail landings per vessel per 24-hour day of fishing effort for vessels landing at New Bedford was calculated as a measure of relative apparent abundance on each of the three principal yellowtail grounds for the period October 1942 - December 1961.

The terms used here for describing yellowtail abundance and their definitions (Marr, 1951) are given below. *Abundance* is the absolute number of individuals in a population. *Availability* is the degree (a percentage) to which a population is accessible to the efforts of a fishery. *Apparent abundance* is the abundance as affected by availability, or the absolute number of fish accessible to the fishery. Landings per unit effort measures apparent abundance rather than absolute abundance. Because landings per unit effort for a particular period is only relative to similar measures for other periods, it is considered a measure of *relative apparent abundance*.

Vessels landing yellowtail at New Bedford range in size from about 12, to over 100 registered gross tons. The vessel size composition of this fleet varies from season to season and from year to year for reasons given earlier. Yellowtail catching power varied with vessel size, and it was therefore necessary to take into account changes in the vessel size composition of the fleet for the landings per day calculations. To do this the vessels were divided into four tonnage groups: under 26, 26-50, 51-75, and 76-100 gross tons. Each of these groups was treated as a separate fleet for the calculations; comparisons and combinations of data were made in final analyses.

A definition of yellowtail fishing effort was required for the landings per day calculations. Because yellowtail are actively fished on grounds where other species are fished, including cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), redhake (*Urophycis chuss*), silver hake (*Merluccius bilinearis*), winter and summer flounder, it was inaccurate to define all effort on these grounds as yellowtail effort. It was not feasible, using available fishing area data from interviews, to define yellowtail fishing areas within these grounds with sufficient precision so that all effort within certain areas could safely be treated as yellowtail effort. As an aid in deciding what effort might reasonably be considered yellowtail effort and what effort was expended for other species, frequency distributions of the proportions of yellowtail in New Bedford dragger catches were drawn up, as was suggested by ICNAF (1960) for dealing with mixed species grounds. These are given in Table 3 for 1954 and 1961, years of low and high yellowtail apparent abundance, respectively. It will be seen that these distributions were similar in form in both years. The proportion of yellowtail in trips was either high or low, with relatively few trips falling in the intermediate categories. It was inferred from the form of these distributions that effort intentionally directed toward yellowtail was the effort of trips landing mostly yellowtail. Based partly on this analysis yellowtail effort was therefore defined as that of trips whose landings consisted of 50 per cent or more yellowtail, and this effort alone was used in landings per day calculations⁴.

From questioning New Bedford fishermen and examining trip interview data for that port it was learned that when yellowtail was the principal species being sought during a trip, the catch

⁴Royce *et al.* (1959) calculated average landings per day, 1942-49, for vessels of 26-50 tons landing 75 per cent or more yellowtail at New Bedford from the southern New England ground.

consisted of at least 50 per cent yellowtail. It was therefore believed that in restricting from consideration trips whose yellowtail catch was less than 50 per cent of the total catch, the fishing effort intentionally directed toward yellowtail

TABLE 3. Percentage of yellowtail flounder in landings of New Bedford otter trawler trips in 1954 and 1961.

Percentage Yellowtail	Number of trips	
	1954	1961
0	1071	668
Up to 9	805	438
10 - 19	107	147
20 - 29	45	97
30 - 39	31	82
40 - 49	33	88
50 - 59	36	90
60 - 69	51	128
70 - 79	43	172
80 - 89	83	271
90 - 100	265	842
Totals	2570	3023

TABLE 4. Percentages of total yellowtail landings included in landings per day calculations for the 3 principal grounds, 1943-61.

Year	Southern New England Ground	Georges Bank	Cape Cod Ground
1943	50.3	15.6	6.2
1944	36.4	43.9	9.9
1945	47.3	36.0	1.5
1946	54.8	26.2	2.9
1947	55.6	13.3	10.5
1948	58.2	40.9	3.0
1949	51.8	42.4	10.8
1950	37.0	52.0	10.2
1951	31.1	57.6	22.6
1952	30.9	48.3	26.4
1953	45.6	54.3	22.2
1954	26.8	74.7	17.4
1955	43.6	61.1	22.8
1956	44.0	78.2	8.3
1957	50.2	76.5	17.1
1958	61.6	85.3	4.3
1959	55.5	72.2	2.7
1960	61.8	67.6	5.8
1961	69.0	69.1	5.4

was included in the calculations, and that effort for other species was, for the most part, excluded.

Percentages of annual yellowtail landings from the three grounds used in the landings per day calculations are given in Table 4. For the southern New England ground and Georges Bank these averaged about 48 and 53 per cent, respectively, including therefore a large part of total landings from these grounds. For the Cape Cod ground the proportion of landings included in the calculations was small, less than 10 per cent of total landings in many of the years. Because of this the landings per day figures for this ground may be considered less reliable for estimating apparent abundance than were data from the other grounds.

Vessels of the 26-50 ton group were chosen as the standard yellowtail fishing vessels, because boats of these sizes most consistently expended a large effort toward yellowtail. For analysis it was desirable to calculate, for a given ground, landings per standard day values (i.e., in terms of the 26-50 ton vessels) that included catch and effort data of all vessel size groups combined. This was done by first adjusting the recorded days fished for each vessel group by its fishing power relative to that of 26-50 ton vessels and by then calculating landings per day using the adjusted days fished⁵.

An estimate of overall fishing intensity directed toward yellowtail on each ground in each year in 1943-61 was obtained by dividing total yellowtail catch, by landings per standard day fished. This gave values of total yellowtail fishing effort in standard days.

Yellowtail landings, fishing effort, and landings per day of fishing effort for the three New England grounds are discussed below. The southern New England ground is considered first.

2. Southern New England Ground

The southern New England ground supplied most of the yellowtail catch before 1948. Landings from there for the early part of the period 1942-61 were high, reaching a peak of about 63 million pounds (28,600 metric tons) in 1942 (Table 2, Fig. 2). A catch decline followed this, reducing annual landings to less than 10 million pounds (4,540 metric tons) for much of the 1950's. Following the 1954 low of 3.3 million pounds

⁵ The procedure for this adjustment is given in an appendix; the adjusted values are given in Table A-1.

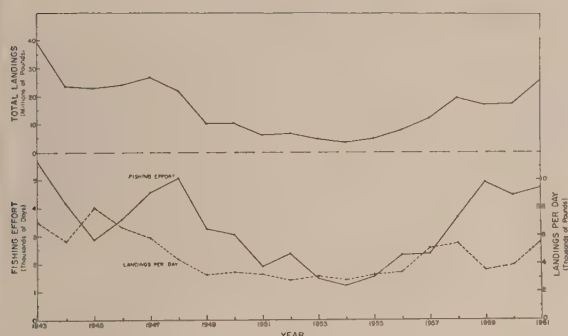


Fig. 2. Yellowtail landings per standard day, fishing effort in standard days, and total landings for the southern New England ground, 1943-61.

(1,500 metric tons) there has been a marked upward trend in catch, however, bringing landings to over 25 million pounds (11,300 metric tons) in 1961.

Average annual landings per standard day and total fishing effort in standard days on the southern New England ground for all vessels in 1943-61, adjusted to the fishing power of 26-50 ton vessels, are shown in Fig. 2 along with landings. The relative apparent abundance of yellowtail, as shown by landings per standard day, was high in the early part of the period, rising to 8,000 pounds (3.6 metric tons) in 1945 (Fig. 2). During the late 1940's and early 1950's it dropped to less than half of the 1945 peak, but in a number of years it has shown substantial increases. Overall patterns for landings and relative apparent abundance were similar.

Average landings per day and recorded days fished by season and year for October 1942 to December 1961 for interviewed boats of under 26, 26-50, 51-75, and 76-100 gross tons are given in Table A-2. These data show that apparent abundance generally was lowest in the second quarter, the spawning season, and highest in the third and fourth quarters. This seasonal pattern is similar to that shown by Royce *et al.* (1959) in their study of yellowtail from the southern New England ground, 1942-49, and it probably reflects seasonal changes in yellowtail availability.

The pattern of fishing effort was similar to that of relative apparent abundance in many of the years; however, there were notable exceptions (Fig. 2). One is seen in the middle 1940's when apparent abundance was high but fishing effort was low. This may have resulted in part from

low ceiling prices paid for yellowtail during World War II and from dangers of fishing during the war. In any case, low landings in some years stemmed not from scarcity of fish, but from failure of the fleet to exploit stocks of relatively high apparent abundance.

Fishing effort for yellowtail, especially by smaller boats, dropped markedly in 1949 (Fig. 2, Table A-2). At this time many of the vessels began fishing for industrial species, which had recently come into demand, rather than for yellowtail, since the latter had become scarce. Effort for yellowtail, especially by larger boats, has again increased with the apparent abundance increases of the latter part of the period covered. Average total fishing effort for the 19-year period was 3,315 standard days per year.

3. Georges Bank

Georges Bank is second to the southern New England ground as a yellowtail producing area. Small catches of yellowtail were made there in the early 1940's by vessels whose principal effort was for other species. In addition, a small amount of yellowtail effort was expended on the Cultivator Shoal area of Georges Bank (subarea H) during the late winter and early spring, where concentrations of yellowtail were found in these seasons. Total landings of the early 1940's ranged from 2 to 3.5 million pounds (900 to 1,600 metric tons) per year (Table 2, Fig. 3). From 1947 on, subareas M and N were the most important yellowtail fishing areas on Georges Bank, the fish being caught there during the summer and fall. Increased catches from the Bank as a result of fishing in these subareas raised total landings to a peak of 16 million pounds (7,300 metric tons) by 1949. Following this, landings declined slowly to 3.5 million pounds (1,600 metric tons) in 1956. In 1957-61 they have again increased substantially.

Average annual landings per standard day and total fishing effort in standard days on Georges Bank for all vessels in 1943-61, adjusted to the fishing power of 26-50 ton vessels, are shown in Fig. 3 along with landings. Relative apparent abundance was high during the early part of the period covered, reaching nearly 17,000 pounds (7.7 metric tons) in 1944. This was followed by a decline, reducing apparent abundance to a comparatively stable level of about 5,000 pounds (2.3 metric tons) in 1950-56. A slight apparent

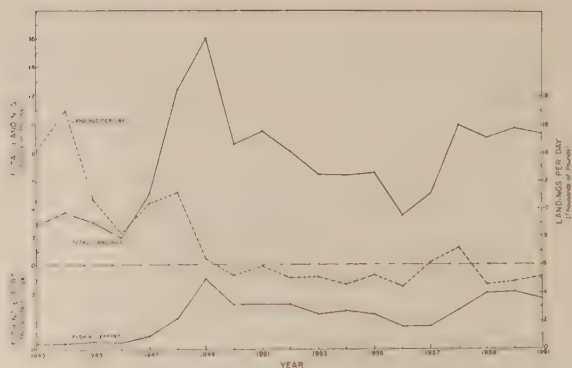


Fig. 3. Yellowtail landings per standard day, fishing effort in standard days, and total landings for Georges Bank, 1943-61.

abundance increase in 1957-58 was followed by a drop to approximately 5,000 pounds (2.3 metric tons) again in 1959-61.

Average landings per day and recorded days fished by season and year for October 1942 to December 1961 for interviewed vessels of 26-50, 51-75, and 76-100 gross tons, the vessel groups that fished this ground are given in Table A-3. Landings per day and fishing effort were highest in the winter months through 1946; following 1946 they were highest in the summer and fall.

Fishing effort on Georges Bank was low from 1943 to 1947, accounting for the low level of landings in these years when relative apparent abundance was high (Fig. 3, Table A-3). Effort increased in 1948 when intensive summer and fall exploitation of yellowtail in subareas M and N began. The high abundance of yellowtail in these subareas at this time, in contrast to the low abundance on the southern New England ground (Fig. 2), resulted in a rapid increase in Georges Bank fishing intensity, and by 1949, when effort and landings reached peaks there, apparent abundance had declined markedly. From 1950 to 1957 fishing effort gradually decreased despite the fairly stable level of apparent abundance in this period. An increase in effort in 1958-59 followed the apparent abundance increase of 1957-58. With the subsequent drop in apparent abundance in 1959-1961, effort increased, maintaining landings at nearly 10 million pounds per year in this period. Average Georges Bank fishing effort in the 19-year period of 1,186 standard days per year was about one third of the annual effort expended on the southern New England ground in the same period.

4. Cape Cod Ground

The Cape Cod ground is of least importance, in terms of landings, of the three principal grounds (Table 2, Fig. 4). During most of the period covered, the catch there was relatively stable at about 2 to 3 million pounds (900 to 1,400 metric tons) per year. Following 1953 it has increased, however, with peak landings of 5 million pounds (2,300 metric tons) being obtained in 1957.

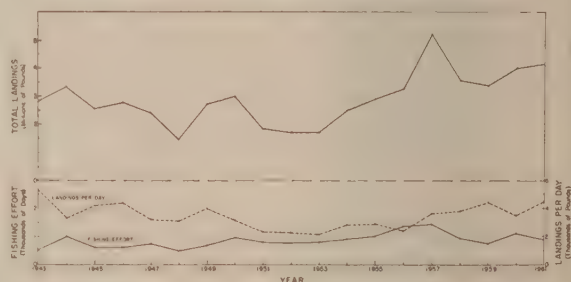


Fig. 4. Yellowtail landings per standard day, fishing effort in standard days, and total landings for the Cape Cod ground, 1943-61.

Annual landings per standard day and total fishing effort in standard days on the Cape Cod ground for all vessels in 1943-61, adjusted to the fishing power of 26-50 ton vessels, are shown in Fig. 4 with total landings. Average landings per day and recorded days fished in this period by interviewed New Bedford vessels of under 26, and 26-50 gross tons, data from which landings per standard day was calculated, are given in Table A-4. Annual landings per standard day was highest in 1943, dropped to its lowest point in the early 1950's, and increased again in the latter part of the period. Since, as mentioned earlier, only a small part of total landings from this ground were included in the landings per day calculations for some years (Tables 4, A-4), they cannot be considered as valid an estimation of relative apparent abundance here as on the other grounds. They are useful, however, in that they provide a broad picture of abundance fluctuations on this ground. The data show that apparent abundance of yellowtail on the Cape Cod ground was considerably lower than on the other principal grounds in most years and that it fluctuated less. It was highest in the early part of the period covered, declined in the early and middle 1950's, and increased again in recent years.

Yellowtail fishing effort also remained stable compared with that on the other grounds. Average annual effort was about 860 standard days.

Discussion

The patterns of relative apparent abundance of yellowtail on the southern New England ground and Georges Bank, after the period of initial exploitation, generally were similar to the patterns of landings. Landings per unit effort on Georges Bank was high on initial exploitation, and it declined when stocks that had been accumulated in years of little fishing were cropped down following increased fishing in 1948 and 1949 (Table A-3, Fig. 3). Relative apparent abundance data for the southern New England ground do not date back far enough to show what happened in the early years of the fishery on this ground. Landings per day there of 11,000 pounds (5 metric tons) and fishing effort of 6,264 days in 1942, calculated by Royce *et al.* (1959) from log book records, and the data of Table A-1 for subsequent years, indicate that apparent abundance was declining in the early 1940's. From what is known about the yellowtail fishery of these years, this coincided with a period of expanding exploitation on this ground.

While exploitation has reduced the size of the catchable population, there is no clear evidence from data presented here that overfishing has occurred. There is, in fact, some indication that, following initial exploitation, apparent abundance has varied independently of the fishery. This is indicated on the southern New England ground, for example, where apparent abundance has increased in recent years during a period of increasing fishing effort (Fig. 2, Table A-1).

The correlation coefficients between average landings per standard day and a three-year moving total of effort (the annual effort plus effort of the previous two years) for the three grounds in 1945-61 provided further information on the relation of stock abundance to effort (Table A-1, Fig. 5). For the southern New England ground $r = 0.46$ ($p = 0.07$), indicating that in the period covered the stock level has not been reduced by the amount of effort expended. The positive correlation suggests instead that the fishing level has followed, rather than preceded, the changes in apparent abundance, increasing when apparent abundance rose. A pattern of this kind might be expected in a mixed species fishery such as that of New England in which fishermen may change their effort to species other than yellowtail when it becomes profitable.

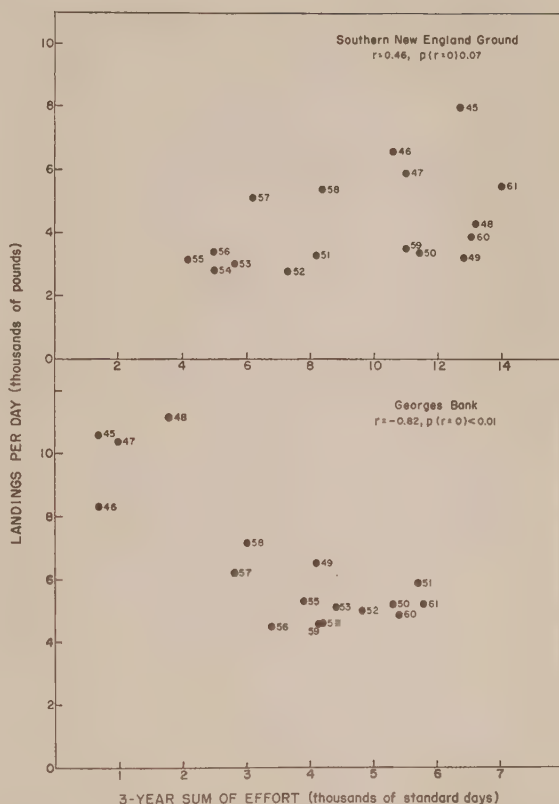


Fig. 5. The relationships between yellowtail apparent abundance and three-year sums of yellowtail effort for the southern New England ground and Georges Bank, 1945-61.

For Georges Bank the negative correlation coefficient between fishing effort and apparent abundance ($r = -0.82$, $p < 0.01$) shows that the stock level dropped during the period of increasing effort, indicating that fishing had a significant effect on the stock on this ground (Fig. 5). Apparent abundance level from 1949 on was about half that of the pre-1949 period when the stock was relatively unfished. As the data of Fig. 5 show, however, fluctuations in apparent abundance from 1949 on were not obviously related to variations in effort.

For the Cape Cod ground the correlation coefficient between effort and apparent abundance of 0.11 ($p > 0.50$) suggests that there was no relationship between stock abundance and effort on this ground in the period covered.

The effort and apparent abundance data for both the southern New England ground and

Georges Bank in the latter part of the period covered further suggested that fishing level has lagged behind, rather than preceded, apparent abundance changes (Fig. 2 and 3). When apparent abundance increased in 1957-58, there was no corresponding increase in fishing effort until 1958. Similarly, effort remained high in 1959-60 although apparent abundance had declined.

Total fishing effort on the New England grounds averaged about 5,400 standard days per year. Approximately 62 per cent of this was expended on the southern New England ground, 22 per cent on Georges Bank, and 16 per cent on the Cape Cod ground.

The patterns of relative apparent abundance on the three grounds show that there was some correspondence from ground to ground in broad trends in yellowtail apparent abundance (Fig. 6, Table A-1). This correspondence suggests that conditions influencing apparent abundance level operated on all grounds simultaneously.



Fig. 6. Yellowtail flounder landings per standard day for the three principal New England grounds, 1943-61.

As noted in the introduction, Royce *et al.*, (1959) concluded that yellowtail catch variations in the 1940's resulted from natural fluctuations in availability and abundance. They suggested that a warming trend may have effected temporary northeastward shifts in population centers, increasing yellowtail availability on the southern New England ground in the early 1940's and on Georges Bank a few years later. Past work has shown that southern New England ground yellowtail normally move toward the east in the summer months and toward the west in winter, possibly in response to seasonal temperature changes (Royce *et al.*, 1959; Lux, 1963). An eastward

movement there in summer is in the direction of cooler water (Bigelow, 1933).

There has indeed been a marked upward trend in temperature in New England, especially in the winter, in the period in which yellowtail have been exploited (Fig. 7). Surface water temperature at Boothbay Harbor, Maine, and at other temperature stations, reached a peak in the early 1950's and declined slightly in 1955-61 (Taylor, Bigelow, and Graham, 1957; Bumpus, 1957a and b; Day, 1959a and b, 1960, 1963)⁶. Taylor *et al.*, also found evidence of northward shifts in abundance and distribution of a number of marine animals in the period of rising temperature.

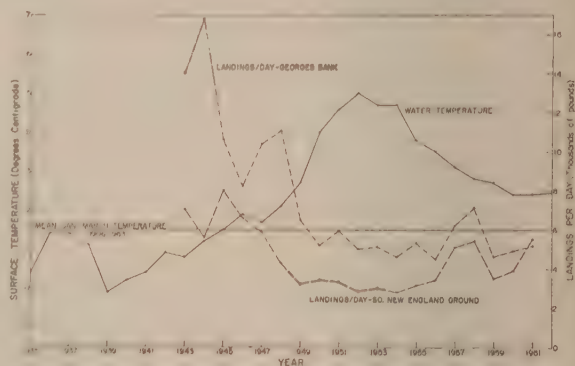


Fig. 7. Winter (January-March) surface water temperature at Boothbay Harbor, Maine in 1935-62, smoothed by 3's, and yellowtail landings per standard day for the southern New England ground and Georges Bank in 1943-61.

Yellowtail apparent abundance on the southern New England ground and Georges Bank dropped to its lowest level at about the time when temperature reached its peak in the early 1950's; it subsequently increased in 1957-58 during a period of decreasing temperature (Fig. 7). The pattern suggested that there was an inverse relationship between temperature and yellowtail apparent abundance, but, as the data show, this was not clear cut. The correlation coefficient between mean January - March temperature for each year (unsmoothed data) and average landings per standard day in the same year in 1943-61 for the southern New England ground was significant at the 5 per cent level ($r = -0.70$, $p < 0.01$), while that for Georges Bank in 1948-61 was not significant ($r = -0.48$, $p = 0.09$).

⁶Boothbay Harbor water temperatures for 1956-63 were obtained from unpublished data, U.S. Dept. of the Int., Bur. Comm. Fish. Biological Laboratory, Boothbay Harbor.

Boothbay Harbor temperature data comprise the only unbroken New England water temperature record covering the period 1943-61. While shoreline temperature undoubtedly reflects to some degree the trend in bottom temperature offshore on the fishing grounds, comparison between Boothbay Harbor January - March surface temperature and that recorded on lightships some distance from shore failed to show a high degree of association. The correlation coefficient between temperature at Boothbay Harbor and Portland lightship (43° 32' N, 70° 06' W; depth 27 m), using the 23 years comparable data given by Bumpus (1957a), although significant ($r = 0.61$, $p < 0.01$), was not high. The correlation between temperature at Boothbay Harbor and Nantucket lightship, moored on the southern New England ground (40° 37' N, 69° 38' W; depth 55 m), using 21 years data, was similar in magnitude ($r = 0.63$, $p < 0.01$). However, the correlation coefficient between January - March temperature recorded at these 2 lightships was not significant ($r = 0.33$, $p = 0.25$), but here only 14 years data were available for comparison.

In view of the inconclusiveness of the above comparisons and of lack of continuous records of bottom temperature on fishing grounds, further analysis of the relationship of climatic change to yellowtail apparent abundance appears to be of little use at present.

Conclusions

1. Fluctuations in yellowtail flounder landings on the principal New England fishing grounds have resulted from variations in apparent abundance and fishing effort.

2. Relative apparent abundance of yellowtail, as shown by landings per day of fishing effort, was high in the early part of the period 1943-61, declined in the late 1940's and early 1950's, and increased again in the late 1950's.

3. Apparent abundance usually was higher on Georges Bank, an offshore ground, than on the southern New England and Cape Cod grounds, which are inshore.

4. Trends in relative apparent abundance were similar on all grounds.

5. The available data provide no evidence that overfishing has occurred on the three New England grounds in the period covered. This

is the conclusion reached by Royce *et al.* (1959) for the southern New England ground alone in 1942-49.

Summary

The New England fishery for yellowtail flounder developed in the 1930's when a demand for the species arose.

Otter trawlers of 45-75 feet (14-23 m) in length are the vessel sizes used. There is no true yellowtail fleet because the activities of the boats vary with season and with price and abundance of a number of species.

New Bedford, Massachusetts, where 75 per cent of the catch currently is landed, is the principal yellowtail port.

Yellowtail are fished on three New England grounds: the southern New England ground (south of Cape Cod), Georges Bank, and the Cape Cod ground (east and north of Cape Cod). Marking experiments indicate that each ground supports a relatively separate yellowtail group, with little movement occurring between grounds.

Total landings have fluctuated widely. They rose to a peak of 68 million pounds (31,000 metric tons) in 1942, declined to a low of 13 million pounds (5,900 metric tons) in 1954, and have risen again to 39 million pounds (17,700 metric tons) in 1961. The southern New England ground usually has supplied most of the landings.

Yellowtail landings per day of fishing effort, as a relative apparent abundance measure, was calculated for each ground for vessels landing 50 per cent or more yellowtail at New Bedford in 1943-61. Results indicated that the patterns of landings and relative apparent abundance were similar. In some years, however, low landings apparently stemmed from low effort on abundant stocks. Apparent abundance usually was highest on Georges Bank and lowest on the Cape Cod ground. Overall patterns of relative apparent abundance were similar on all three of the New England grounds.

Changes in the level of fishing effort often followed changes in apparent abundance level, effort in some cases increasing markedly after a relatively small apparent abundance increase. Total fishing effort for all grounds averaged about 5,400 standard days per year.

There was no evidence that overfishing has occurred. A comparison of New England winter

water temperature with landings per day suggested, however, that there may have been an inverse relationship between temperature and apparent abundance, but this was not clear.

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Appendix

As noted in the text, yellowtail landings per day was calculated for each of the defined vessel size groups that fished yellowtail. The 26-50 ton group was chosen as the standard yellowtail fishing gear, and it was desired to express landings per day for each year, of all vessel groups combined, in landings per standard day fished, that is, in terms of the 26-50 ton group. This was accomplished by dividing total yellowtail landings obtained through the recorded yellowtail effort on a given ground, by total standard days fished in obtaining this catch, as shown in the equation

$$A' = \frac{(DA)_1 + (DA)_2 + (DA)_3 + (DA)_4}{D'_1 + D'_2 + D'_3 + D'_4}$$

in which, for a given year:

the subscripts 1, 2, 3, and 4 refer to the under 26, 26-50, 51-75, and 76-100 ton vessel groups, respectively;

D = days fished for yellowtail by a given vessel group (Tables A-2, A-3, and A-4);

A = landings per day for a given vessel group (Tables A-2, A-3, and A-4);

D' = standard days fished for yellowtail by a given vessel group;

A' = landings per standard day for all vessel groups combined.

To obtain the values for D' for the different vessel groups, the fishing power of each group in relation to fishing power of the 26-50 ton group was calculated. For the southern New England ground, as an example, data in Table A-2 were used. To find the relative fishing power of the under 26 ton vessels, the average landings per day for the entire period for this group, unweighted for fishing effort, was calculated, using annual landings per day data from all years in which 50 or more days of yellowtail fishing effort was

recorded⁷. The resulting average of 4,232 pounds per day was based on annual landings per day for 13 years (1943-50 and 1957-61). Average landings per day for these years for the 26-50 ton vessels, calculated in the same way, was 5,184 pounds. Evidently the fishing power of the smaller vessels was 4,232/5,184 or 0.816 times that of the 26-50 ton vessels. This fishing power factor was used to convert days fished of the smaller vessels (Table A-2) to standard days fished. This same method was used in converting the days fished of 51-75 and 76-100 ton vessels into standard days.

The above procedure, except as noted below for the Cape Cod ground, was followed for the three principal grounds, using data from Tables A-2, A-3, and A-4. Resulting mean landings

per standard day for all grounds are given in Table A-1.

For the Cape Cod ground the data of Table A-4 were considered inadequate for determining relative fishing power of the two vessel groups that fished this ground, since recorded effort was less than 50 days in many of the years. The fishing power factor calculated for the same vessel groups on the southern New England ground was therefore used to convert days fished by the under 26-ton vessels on the Cape Cod ground to standard days.

Total fishing effort in standard days fished, by year for each ground, was obtained by dividing the total yellowtail landings (Table 2) by landings per standard day (Table A-1). The resulting fishing effort figures are given in Table A-1.

TABLE A-1. Total estimated yellowtail fishing effort in standard days fished and average yellowtail landings per standard day in pounds for the principal New England grounds, 1943-61.
(1 metric ton = 2,205 pounds)

Year	Southern New England Ground		Georges Bank		Cape Cod Ground	
	Days fished	Landings per day	Days fished	Landings per day	Days fished	Landings per day
1943	5,681	7,002	198	14,047	529	5,350
1944	4,164	5,621	217	16,881	1,008	3,308
1945	2,852	8,015	282	10,605	606	4,218
1946	3,596	6,636	232	8,264	622	4,457
1947	4,550	5,869	480	10,360	746	3,202
1948	5,047	4,334	1,122	11,116	472	3,101
1949	3,248	3,173	2,493	6,458	677	4,004
1950	3,062	3,391	1,636	5,246	952	3,123
1951	1,889	3,253	1,611	5,900	792	2,345
1952	2,364	2,788	1,596	5,043	760	2,255
1953	1,442	3,023	1,241	5,149	778	2,193
1954	1,200	2,784	1,385	4,595	890	2,773
1955	1,529	3,143	1,234	5,262	996	2,887
1956	2,297	3,399	790	4,452	1,340	2,421
1957	2,396	5,063	821	6,181	1,439	3,610
1958	3,666	5,356	1,400	7,139	925	3,842
1959	4,904	3,479	1,969	4,625	762	4,415
1960	4,439	3,896	2,018	4,858	1,121	3,564
1961	4,686	5,473	1,816	5,158	914	4,535

⁷)A comparison of landings per day of the different vessel size groups for the 19-year period covered suggested that a useful estimate of landings per day could be obtained where 50 or more days fishing effort had been recorded.

TABLE A-2. Days fished and average yellowtail landings per day in pounds for otter trawler trips landing 50 per cent or more yellowtail at New Bedford from the southern New England ground, by vessel size and by calendar quarter and year, 1942-61. (1 metric ton = 2,205 pounds).

Year and Quarter	Vessel Size (Gross Tons)							
	Under 26		26 - 50		51 - 75		76 - 100	
	Days fished	Landings per day	Days fished	Landings per day	Days fished	Landings per day	Days fished	Landings per day
1942								
Oct. - Dec.	161.5	11,102	297.1	8,583	54.5	10,712	—	—
1943								
Jan. - Mar.	277.8	4,993	632.4	5,594	155.6	8,454	—	—
Apr. - Jun.	356.3	4,185	299.0	4,821	9.9	6,749	—	—
Jul. - Sept.	490.3	7,683	392.4	10,280	34.0	18,304	20.7	12,202
Oct. - Dec.	76.5	5,298	209.4	5,493	44.2	8,024	24.8	7,625
Annual Total	1,200.9	5,871	1,533.4	6,628	243.7	9,681	45.5	9,707
1944								
Jan. - Mar.	273.7	4,304	547.6	5,509	63.3	5,925	8.5	5,106
Apr. - Jun.	76.0	4,029	48.2	5,108	—	—	—	—
Jul. - Sept.	153.4	4,558	317.6	6,690	37.6	7,111	6.3	7,798
Oct. - Dec.	3.5	1,707	47.1	4,173	3.1	3,010	—	—
Annual Total	506.6	4,322	960.5	5,814	104.0	6,267	14.8	6,252
1945								
Jan. - Mar.	136.0	4,554	239.7	5,764	35.3	6,274	—	—
April. - Jun.	4.0	5,616	12.3	4,358	—	—	—	—
Jul. - Sept.	167.5	7,396	253.7	9,157	44.8	8,876	—	—
Oct. - Dec.	153.2	7,005	297.3	9,551	64.2	10,080	—	—
Annual Total	460.7	6,412	803.0	8,216	144.3	8,775	—	—
1946								
Jan. - Mar.	122.2	5,726	212.6	6,113	56.3	7,249	—	—
Apr. - Jun.	19.0	4,544	58.2	6,463	1.0	7,750	—	—
Jul. - Sept.	185.5	5,228	367.6	6,883	81.5	6,230	11.1	6,844
Oct. - Dec.	213.1	5,777	545.3	7,066	129.2	7,386	12.1	6,073
Annual Total	539.8	5,533	1,183.7	6,808	268.0	7,007	23.2	6,442
1947								
Jan. - Mar.	82.8	5,064	285.5	5,634	88.3	6,196	12.7	5,298
Apr. - Jun.	136.5	3,817	176.9	4,522	7.4	2,164	—	—
Jul. - Sept.	145.9	6,719	364.6	7,871	82.3	8,648	—	—
Oct. - Dec.	326.5	4,824	756.0	5,295	104.9	5,254	24.9	6,871
Annual Total	691.7	5,054	1,583.0	5,863	282.9	6,455	37.6	6,340
1948								
Jan. - Mar.	193.2	2,927	540.8	3,144	69.5	4,185	13.5	3,076
Apr. - June	152.9	3,524	328.8	3,850	16.0	5,535	—	—
Jul. - Sept.	186.3	4,399	588.1	4,793	60.4	4,703	11.4	7,513
Oct. - Dec.	114.1	4,131	593.4	4,896	104.7	6,478	26.5	6,831
Annual Total	646.5	3,705	2,051.1	4,237	250.6	5,354	51.4	5,996
1949								
Jan. - Mar.	101.6	2,295	725.5	2,534	65.0	2,854	7.0	6,964
Apr. - Jun.	16.5	2,084	91.7	2,429	6.5	2,154	—	—
Jul. - Sept.	4.2	2,547	103.2	4,738	10.0	5,146	12.0	7,135
Oct. - Dec.	45.8	2,966	361.8	3,788	94.7	4,969	24.2	5,954
Annual Total	168.1	2,464	1,282.2	3,058	176.2	4,095	43.2	6,446
1950								
Jan. - Mar.	52.0	2,548	266.2	2,973	62.6	3,225	32.1	3,584
Apr. - Jun.	—	—	12.5	2,233	—	—	—	—
Jul. - Sept.	9.8	4,254	48.9	2,556	3.0	1,027	—	—
Oct. - Dec.	34.2	3,327	437.8	3,852	135.6	4,118	10.5	4,706
Annual Total	96.0	3,000	765.4	3,437	201.2	3,794	42.6	3,860
1951								
Jan. - Mar.	—	—	95.6	2,318	13.5	3,195	4.0	3,750
Apr. - Jun.	—	—	6.4	2,238	4.0	1,781	—	—
Jul. - Sept.	—	—	122.6	3,592	33.6	7,136	4.0	1,406
Oct. - Dec.	7.2	3,538	195.5	3,069	77.4	3,871	—	—
Annual Total	7.2	3,538	420.1	3,038	128.5	4,589	8.0	2,578
1952								
Jan. - Mar.	1.3	2,273	37.4	3,820	8.2	4,417	—	—
Apr. - Jun.	2.0	2,660	—	1,472	—	—	—	—
Jul. - Sept.	4.0	969	65.0	2,179	10.0	4,375	—	—
Oct. - Dec.	9.3	2,126	342.2	2,704	185.9	3,346	22.5	3,930
Annual Total	16.6	1,923	447.6	2,713	204.1	3,439	22.5	3,930
1953								
Jan. - Mar.	7.3	2,171	156.0	2,440	44.0	2,728	2.6	2,571
Apr. - Jun.	1.0	2,125	27.7	2,758	6.5	5,212	—	—
Jul. - Sept.	3.0	1,833	92.2	3,626	47.0	5,484	—	—
Oct. - Dec.	—	—	134.1	3,145	95.5	3,144	5.2	5,920
Annual Total	11.3	2,077	410.0	2,959	193.0	3,689	7.8	4,804
1954								
Jan. - Mar.	10.0	2,611	34.5	2,319	56.2	3,231	14.0	4,107
Apr. - Jun.	—	—	9.8	2,386	—	—	—	—
Jul. - Sept.	4.0	348	7.5	2,639	—	—	—	—
Oct. - Dec.	21.3	1,596	103.8	3,201	40.0	3,142	5.0	2,800
Annual Total	35.3	1,742	155.6	2,927	96.2	3,194	19.0	3,763

LUX: YELLOWTAIL FLOUNDER FISHERY

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TABLE A-2 (continued)

Year and Quarter	Vessel Size (Gross Tons)							
	Under 26		26 - 50		51 - 75		76 - 100	
	Days fished	Landings per day	Days fished	Landings per day	Days fished	Landings per day	Days fished	Landings per day
1955								
Jan. - Mar.	8.6	1,875	127.2	2,840	34.1	3,330	17.5	3,018
Apr. - Jun.	2.0	1,237	7.0	2,969	—	—	—	—
Jul. - Sept.	4.0	719	24.2	4,661	1.5	9,817	—	—
Oct. - Dec.	14.0	1,328	264.9	3,267	114.7	3,882	18.0	3,772
Annual Total	28.6	1,401	423.3	3,213	150.3	3,816	35.5	3,400
1956								
Jan. - Mar.	30.1	2,354	117.3	2,503	58.5	2,633	1.0	3,750
Apr. - Jun.	—	—	16.7	3,331	10.5	4,401	—	—
Jul. - Sept.	11.1	2,667	121.1	4,236	45.5	4,563	—	—
Oct. - Dec.	6.8	3,299	380.5	3,718	160.0	3,614	9.5	5,408
Annual Total	48.0	2,560	635.6	3,582	274.5	3,593	10.5	5,250
1957								
Jan. - Mar.	7.0	3,356	230.2	3,388	76.0	4,116	8.5	4,634
Apr. - Jun.	1.0	2,500	24.5	3,392	4.5	4,667	—	—
Jul. - Sept.	21.4	1,965	74.5	3,579	20.5	5,530	18.7	2,333
Oct. - Dec.	24.5	5,269	307.3	6,495	266.1	7,257	40.5	7,014
Annual Total	53.9	3,658	636.5	4,911	367.1	6,478	67.7	5,422
1958								
Jan. - Mar.	39.5	5,366	304.0	4,908	166.2	5,215	40.5	5,028
Apr. - Jun.	8.0	3,929	97.2	4,072	72.2	3,196	4.3	3,284
Jul. - Sept.	6.4	5,816	166.1	6,111	59.6	6,390	12.8	6,948
Oct. - Dec.	10.8	3,928	562.9	5,954	440.4	6,643	106.1	7,626
Annual Total	64.7	4,993	1,130.2	5,534	738.4	5,964	163.7	6,816
1959								
Jan. - Mar.	37.8	2,696	462.8	3,425	157.0	3,942	30.0	4,672
Apr. - Jun.	5.2	3,540	186.1	3,453	81.0	2,880	17.0	3,094
Jul. - Sept.	6.5	4,590	201.3	5,524	188.8	6,277	15.8	5,979
Oct. - Dec.	39.3	2,098	546.4	3,030	468.3	3,400	93.2	3,468
Annual Total	88.8	2,619	1,396.6	3,576	895.1	4,055	156.0	3,913
1960								
Jan. - Mar.	48.1	1,780	451.8	2,575	188.4	3,869	19.2	3,785
Apr. - Jun.	36.5	2,281	117.8	2,205	40.3	2,234	21.2	4,682
Jul. - Sept.	20.7	3,852	395.6	4,374	191.6	4,278	39.9	4,460
Oct. - Dec.	52.8	4,369	515.9	5,017	373.4	5,802	78.6	5,219
Annual Total	158.1	3,031	1,481.1	3,877	793.7	4,794	158.9	4,221
1961								
Jan. - Mar.	83.4	3,790	508.4	4,246	348.5	4,607	50.0	6,415
Apr. - Jun.	44.5	2,986	239.7	3,463	99.7	3,769	5.0	4,835
Jul. - Sept.	20.5	5,808	392.3	5,352	177.4	5,930	40.9	7,138
Oct. - Dec.	32.9	6,741	452.5	7,866	482.2	8,443	51.2	10,041
Annual Total	181.3	4,356	1,592.9	5,429	1,107.8	6,413	147.1	7,824

TABLE A-3. Days fished and average yellowtail landings per day in pounds for otter trawler trips landing 50 per cent or more yellowtail at New Bedford from Georges Bank, by vessel size and by calendar quarter and year, 1942-61. (1 metric ton = 2,205 pounds).

Year & Quarter	Vessel Size (Gross Tons)					
	26 - 50		51 - 75		76 - 100	
	Days fished	Landings per day	Days fished	Landings per day	Days fished	Landings per day
1942						
Oct. - Dec.	3.1	28,703	9.4	16,037	2.9	32,025
1943						
Jan. - Mar.	5.6	14,786	16.7	14,932	5.2	19,455
Apr. - Jun.	—	—	—	—	—	—
Jul. - Sept.	—	—	—	—	—	—
Oct. - Dec.	—	—	—	—	—	—
Annual Total	5.6	14,786	16.7	14,932	5.2	19,455
1944						
Jan. - Mar.	17.7	13,103	40.8	21,769	19.8	18,482
Apr. - Jun.	—	—	—	—	—	—
Jul. - Sept.	—	—	—	—	—	—
Oct. - Dec.	—	—	6.4	19,756	—	—
Annual Total	17.7	13,103	47.2	21,496	19.8	18,482
1945						
Jan. - Mar.	12.1	6,748	27.9	7,184	37.8	17,527
Apr. - Jun.	—	—	—	—	—	—
Jul. - Sept.	—	—	9.0	14,076	—	—
Oct. - Dec.	0.3	12,867	—	—	—	—
Annual Total	12.4	6,896	36.9	8,865	37.8	17,527
1946						
Jan. - Mar.	2.5	13,259	24.7	9,925	13.7	8,507
Apr. - Jun.	—	—	—	—	—	—
Jul. - Sept.	—	—	10.9	8,962	—	—
Oct. - Dec.	—	—	—	—	—	—
Annual Total	2.5	13,259	36.5	9,630	13.7	8,507

TABLE A-3 (continued)

Year & Quarter	Vessel Size (Gross Tons)					
	26 - 50		51 - 75		76 - 100	
	Days fished	Landings per day	Days fished	Landings per day	Days fished	Landings per day
1947						
Jan. - Mar.	—	—	—	—	—	—
Apr. - Jun.	—	—	—	—	—	—
Jul. - Sept.	1.8	5,586	5.8	8,966	—	—
Oct. - Dec.	1.9	7,871	13.5	13,016	30.6	13,377
Annual Total	3.7	6,759	19.3	11,799	30.6	13,377
1948						
Jan. - Mar.	—	—	15.0	8,228	7.2	9,021
Apr. - Jun.	—	—	—	—	—	—
Jul. - Sept.	117.0	11,008	55.1	13,485	112.9	15,629
Oct. - Dec.	39.4	8,548	21.8	10,806	37.9	14,287
Annual Total	156.4	10,388	91.9	11,991	158.0	15,006
1949						
Jan. - Mar.	20.1	3,986	19.5	6,482	2.9	17,210
Apr. - Jun.	51.6	3,909	7.9	5,839	4.8	5,313
Jul. - Sept.	261.3	6,580	154.9	8,365	119.8	8,831
Oct. - Dec.	125.2	6,088	103.6	7,075	93.2	7,798
Annual Total	458.2	6,031	285.9	7,699	220.7	8,428
1950						
Jan. - Mar.	—	—	—	—	—	—
Apr. - Jun.	76.0	3,937	42.3	4,170	5.0	3,710
Jul. - Sept.	346.9	5,146	267.8	6,884	87.0	6,052
Oct. - Dec.	34.3	5,908	18.8	4,620	—	—
Annual Total	457.2	5,002	328.9	6,406	92.0	5,925
1951						
Jan. - Mar.	—	—	—	—	—	—
Apr. - Jun.	20.5	5,705	18.3	6,223	3.5	4,064
Jul. - Sept.	282.2	5,178	143.4	7,953	46.5	7,113
Oct. - Dec.	76.8	6,178	121.1	6,597	15.5	9,278
Annual Total	379.5	5,409	282.8	7,260	65.5	7,463
1952						
Jan. - Mar.	—	—	—	—	—	—
Apr. - Jun.	58.5	4,484	30.0	5,049	4.0	7,156
Jul. - Sept.	331.8	5,147	203.5	5,721	48.0	6,399
Oct. - Dec.	66.6	5,182	48.5	5,127	23.0	6,832
Annual Total	456.9	5,068	282.0	5,547	75.0	6,572
1953						
Jan. - Mar.	—	—	—	—	—	—
Apr. - Jun.	35.4	3,960	29.3	4,461	—	—
Jul. - Sept.	307.0	4,663	231.1	5,543	63.2	5,852
Oct. - Dec.	121.0	6,848	73.1	6,996	8.5	9,505
Annual Total	463.4	5,180	333.5	5,766	71.7	6,285
1954						
Jan. - Mar.	—	—	—	—	—	—
Apr. - Jun.	52.5	4,435	46.0	4,529	20.7	5,543
Jul. - Sept.	282.7	4,540	182.9	4,530	37.5	6,131
Oct. - Dec.	67.3	5,103	65.9	6,187	31.7	7,513
Annual Total	402.5	4,620	294.8	4,900	89.8	6,483
1955						
Jan. - Mar.	—	—	—	—	—	—
Apr. - Jun.	59.0	4,250	41.0	4,241	—	—
Jul. - Sept.	270.5	4,717	214.3	5,896	60.5	6,288
Oct. - Dec.	98.8	7,013	84.3	6,765	64.0	7,383
Annual Total	428.3	5,182	339.6	5,912	124.5	6,851
1956						
Jan. - Mar.	—	—	—	—	—	—
Apr. - Jun.	3.7	3,203	10.0	3,300	3.5	2,678
Jul. - Sept.	194.3	4,505	179.4	4,728	67.0	5,778
Oct. - Dec.	27.2	4,972	63.5	5,429	5.5	8,182
Annual Total	225.2	4,540	252.9	4,847	76.0	5,809
1957						
Jan. - Mar.	—	—	—	—	—	—
Apr. - Jun.	10.0	4,473	3.5	7,250	4.5	4,944
Jul. - Sept.	216.0	6,626	203.8	6,568	72.0	6,746
Oct. - Dec.	28.5	7,956	20.8	7,963	15.0	8,317
Annual Total	254.5	6,690	228.1	6,705	91.5	6,915
1958						
Jan. - Mar.	—	—	—	—	—	—
Apr. - Jun.	35.2	5,601	101.0	4,896	13.5	8,852
Jul. - Sept.	253.0	8,174	445.5	8,040	103.5	9,342
Oct. - Dec.	25.3	8,206	69.0	8,608	34.5	8,488
Annual Total	313.5	7,884	615.5	7,588	151.5	9,104
1959						
Jan. - Mar.	—	—	3.0	9,208	—	—
Apr. - Jun.	53.6	4,065	197.4	4,092	34.0	5,833
Jul. - Sept.	242.4	4,796	525.5	5,548	130.5	5,849
Oct. - Dec.	28.6	4,606	50.0	5,232	16.5	5,280
Annual Total	324.6	4,658	775.9	5,172	181.0	5,794
1960						
Jan. - Mar.	2.5	2,550	—	—	—	—
Apr. - Jun.	66.5	3,855	120.7	4,009	35.0	3,668
Jul. - Sept.	295.4	5,234	392.9	5,594	149.7	5,861
Oct. - Dec.	47.9	7,128	89.7	5,963	34.4	7,363
Annual Total	412.3	5,216	603.3	5,331	219.1	5,746
1961						
Jan. - Mar.	5.0	3,045	2.5	3,900	—	—
Apr. - Jun.	61.9	4,878	158.1	4,716	39.5	5,835
Jul. - Sept.	249.6	5,365	440.2	5,901	83.3	5,745
Oct. - Dec.	32.8	6,324	50.0	8,084	17.5	8,078
Annual Total	349.3	5,336	650.8	5,773	140.3	6,062

LUX: YELLOWTAIL FLOUNDER FISHERY

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TABLE A-4. Days fished and average yellowtail landings per day in pounds for otter trawler trips landing 50 per cent or more yellowtail at New Bedford from the Cape Cod ground, by vessel size and year, 1943-61. (1 metric ton = 2,205 pounds)

Year	Under 26 ton vessels		26 to 50 ton vessels	
	Days fished	Landings per day	Days fished	Landings per day
1943	34.6	4,305	4.7	5,814
1944	65.1	3,363	46.4	2,374
1945	5.1	4,668	5.0	2,959
1946	10.9	2,795	8.9	5,492
1947	63.0	2,295	27.1	3,944
1948	9.2	2,668	6.9	2,920
1949	17.4	2,414	58.7	4,258
1950	15.1	2,396	85.2	3,150
1951	33.4	1,809	151.6	2,368
1952	40.2	1,839	168.2	2,255
1953	53.3	1,744	129.2	2,212
1954	24.6	2,435	134.8	2,742
1955	44.0	1,730	191.2	3,031
1956	24.2	1,604	91.0	2,520
1957	33.0	3,167	219.0	3,577
1958	11.5	2,919	30.1	3,926
1959	7.9	4,332	14.3	4,016
1960	17.7	2,828	50.1	3,593
1961	26.3	4,107	27.6	4,149





